THE STEAM-ENGINE.

THE

STEAM-ENGINE;

A POPULAR ACCOUNT OF ITS

CONSTRUCTION, ACTION, AND HISTORY;

AND A DESCRIPTION OF ITS VARIOUS FORMS;

WITH

A SKETCH OF THE LAWS OF HEAT AND PNEUMATICS; AND
A CRITIQUE ON M. ARAGO'S "ÉLOGE OF WATT."

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"Elements of Physical Geography," &c.

ILLUSTRATED BY FORTY WOOD ENGRAVINGS.

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PREFACE.

The Steam-Engine is so interesting a subject—from the extent and variety of its applications, the great power with which it has armed mankind, the varied forms in which it meets us at every turn, the singular ingenuity of its construction, the beautiful mechanical contrivances which it presents, and the great laws of nature which it illustrates—that there are few who do not desire some knowledge of its structure and mode of action.

The present work is designed to furnish to the general reader such an account of this great machine as may be easily understood by those who are previously unacquainted with the subject. The general laws of HEAT and PNEUMATICS, on which the action of the engine depends, are fully detailed; its construction and mode of action are minutely explained, so that, with the aid of the figures, it may be readily

understood, even by those who have never seen an engine; and the different forms into which the engine is thrown, to fit it for its various applications, are separately described. A sketch of its origin and progress is given, as every one must be desirous to know something of the history of an invention, second only to that of Printing in the magnitude of the results which have flowed from it, and far surpassing that operation in the genius displayed in its conception, and the points of interest it offers to the intelligent observer.

It is hoped that this little work may furnish the general reader with all that he requires on the subject of the Steam-Engine, and enable him, when he meets one, to observe its motions with that interest and enjoyment which are derived from some acquaintance with its structure; and that it may be useful as a guide to teachers in imparting to their pupils a knowledge of the principles, construction, and action of the "Great Machine."

By curtailing some portions of the work, and by condensation, the author has been enabled to add a considerable amount of new matter in the present edition; and it has been re-modelled, so as to render

it more suitable for the purpose of self-instruction, as a popular introduction to the study of Practical Science.

To the present edition, a "Critique on M. Arago's Éloge of James Watt," is appended, which was read some years since before the Philosophical Society of Glasgow, published at the request of the Society, and favourably received as an exposition of the state of the question between the French and the British as to the invention of the Steam-Engine.

NOTTINGHAM, *May*, 1851.

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THE STEAM-ENGINE.

INTRODUCTION.

1. The Steam-Engine is a machine for the production of motion, in which steam (the vapour of boiling water) is used. A machine (from the Greek *mechané*, through the Latin *machina*) in the sense now generally understood, means a contrivance for *applying* to some object a continuous and regular motion, as a spinning wheel, a loom, a watch or clock. If we choose to extend the term so as to include such contrivances as a gun, a mortar, a bow and arrow, a sling, we must at all events carefully distinguish between those which give a continuous and regulated movement, and those which only impart a sudden, irregular, and quickly terminated impulse. The Steam-Engine is a sort of *primary machine*, the object of which is the *production* of force, or moving power, by means of which continuous motion may be communicated to other bodies—as the wheels of a carriage; paddles or oars for propelling vessels on water; the rod of a

pump for raising water; grindstones for reducing bodies to powder; machinery for spinning, weaving, turning, hammering, boring, communicating pressure, &c.

2. MOTION is the general object of all machines: and, in every description of machinery, there are two parts which must be carefully distinguished:—*First*, The machinery which comes into immediate contact with the substance to effect some change upon which is the ultimate object of the operation; *Second*, The engine, or *great machine*, which sets that lesser machinery in motion. The latter is called the *first mover*, *first moving power*, or *prime mover*. The prime mover *produces* the motion; the secondary machinery *applies it*.

3. In a common turning lathe, or in the case of the hand-pump for raising water; in the windmill; or the water-wheel for moving a grindstone—the MAN who, by his muscular power, sets the turning lathe in motion, or works the handle of the pump; the VANES OF THE WINDMILL; and the WATER-WHEEL—are the first movers. It is in these that the motion commences—their object being simply *the production of moving power*, which has to be transmitted from them to the machinery which comes into immediate contact with the wood to be turned, the water to be raised, or the corn to be ground.

The steam-engine is a FIRST OR PRIME MOVER.

4. In every case of the production of motion by machinery, the first mover is simply an engine, or

machine, so constructed as to take advantage of some *natural properties of bodies which are capable of giving rise to motion.* In describing the steam-engine, then, there are two things to be considered: —*First,* Those natural powers resident in bodies from which we procure a force, or moving power; *Second,* The machine, or engine, by which those powers are made effective for the general production of motion. We shall first direct our attention to the former—the source and mode of action of the natural forces, which, in the steam-engine, give rise to the motion.

5. Infinitely various as the different kinds of power may at first sight appear, and however complex the machinery by which they are applied so as to produce motion, upon analysing them, it will be found that there are only *three sources* from which we can obtain a force, or moving power— Animal Strength, Attraction, and Repulsion.

6. Of these, the first and most obvious, and the only one within reach of man in the rude or savage state,—or indeed the only one at his command without considerable progress in the arts,—is the Muscular Power of Animals, or, as it is frequently called, Animal Strength. This source of power resides in the muscles—long, fleshy bodies of a fibrous structure, fixed at each extremity, and possessed of the property of contracting (diminishing in length), in obedience to the will of the animal. By this contractile power, the more movable of the points to which the extremities of the muscle

are attached, is made to approach the other. These muscles are possessed of great strength, being capable, as has sometimes happened, of breaking the bone to which they are attached. We have familiar examples of the application of this power, in the plough, carts, and carriages, canal-boats, horse and cattle mills, all set in motion, and continued in that state by the contractile power of the muscles of animals. The muscular force of man himself, too, has been used as a source of power. It is to be hoped, however, that the steam-engine will ultimately every where supersede the employment of man as a means of mere animal strength; and enable him to limit the exercise of his muscular power to those cases where tact, skill, delicacy of adjustment, and adaptation to varying circumstances are required—where the superior power of an intelligent being, which no machine can imitate, is called into play—in short, that man shall cease or abate the direct exercise of brute force, and employ himself in the higher operation of guiding and controlling it.

This power is not made use of in the steam-engine; but the power of an engine is generally estimated by a measure of force derived originally from comparison with the number of horses that would be required to do the same work—the first steam-engines having been used chiefly as substitutes for horse labour.

7. The other two sources of moving power are —*First*, THE ATTRACTION WHICH EXISTS BETWEEN

BODIES, and tends to make them approach each other; and, *Second,* THE REPULSIVE POWER, which exists, more or less, in all bodies, and tends to drive their particles asunder. These influences are universally diffused through bodies, and are antagonists—*i. e.,* opposed to each other in their action. To the operation of these fundamental properties of matter, all the phenomena of inanimate nature can be traced; and animate beings, though endowed with the independent principle of *life,* are in no small degree subject to their control while living, and when dead are solely obedient to the laws of these great powers.

They act with great energy, and both have been used as sources of power in the steam-engine. The first is applied in some kinds of engines only (now called atmospheric engines); the latter, either applied directly as a moving power, or used to prepare for the action of the attractive force, has been a leading element in the operation of every sort of steam-engine; and as steam is the medium through which the repulsive power is introduced, all are called *steam-engines,* although the steam may not be the direct cause of the motion. At first they were termed *fire-engines,* the steam being formed by the action of fire upon water.

8. The attractive force was taken advantage of by man as a moving power—as in the water-wheel, the windmill, the common pump—long before the repulsive principle was applied, or even thought of, as a source of motion. Now, however, this

great power, so long overlooked, has almost entirely superseded the other; acting in the form of steam, it is seen everywhere, and is the prime mover chiefly employed by civilised nations of modern times. For ages a hidden treasure, it has at last been brought to light; and has placed within the reach of mankind a force so enormous, that it is limited only by the strength of the materials which must be employed to give it effect; a power unremitting in its labours, and universal in its application; so versatile, that it may be transferred from place to place, worked at any time, and suspended or set in action again at a moment's warning;—and withal so steady and regular, so completely under our control, and possessed of a self-regulating property to such an extraordinary extent, that it almost realises the fable of Prometheus, and may fitly be compared to an intelligent being devoted to our service. The repulsive energy is the source of the power of gunpowder as well as that of steam; so that, when we consider the great change effected by the use of gunpowder in warfare, and the vast and various influences of the steam-engine, this remarkable principle may be said to have twice revolutionised the world.

PART I.*

OF ATTRACTION AND REPULSION,

AND THEIR APPLICATION AS MOVING POWERS; INCLUDING THE LAWS OF PNEUMATICS AND HEAT.

9. EXCLUDING the vital energy, then, there are two great powers which are (one or other, or both) concerned in producing all the motions and changes which we see going on around us—ATTRACTION and REPULSION.

10. As the latter, Repulsion, is called into action in an unusual degree in bodies which are heated, while its power seems to diminish in proportion as they are cooled, it has generally been regarded as identical with the influence which gives rise to the phenomena of heat.

SECTION I.

ATTRACTION.

11. THE universal *influence*, Attraction, which operates in drawing bodies and the particles of bodies together,

* The history and description of the Steam-Engine commence at paragraph 168. The previous part consists of a popular account of the laws of Heat and Pneumatics, and the Chemistry of Air, Fuel, Water and Iron.

and retaining them in contact, is of several kinds,* of which two chiefly must be attended to in the consideration of force or motion:—*First,* that which forms bodies into coherent masses, acting between their *minute particles* only when in contact (at insensible distances), called the *attraction of cohesion, attraction of aggregation,* or simply *cohesion;* illustrated by the firmness with which the particles of a piece of iron or marble adhere to each other: and, *Second,* that which brings and retains *bodies* near to each other, acting at sensible or apparent (indeed at all possible) distances, called the *attraction of gravitation,* or simply *gravitation,* illustrated by a stone falling to the ground when left in the air unsupported.

12. Probably the phenomena of every kind which consist in a drawing together or holding together of bodies, are the result of one fundamental power. But it is convenient to subdivide them, and to make distinctions between the different effects produced.

CHAPTER I.

ATTRACTION OF COHESION.

13. When we attempt to break a piece of wood, stone, glass, ice, or any other solid, we find that its particles are firmly bound to each other, and that the exertion of

* We here omit *chemical attraction* or *affinity, electric attraction,* and *magnetic attraction.* The first, acting between the particles of *different* bodies, unites them together, gives rise to new varieties of bodies, and to the phenomena of combination and decomposition; but is not a source of visible motion. The two latter give rise to distinct motion; but the moving power exerted has hitherto been considered

a considerable force is necessary before we can effect a separation. The force which binds the particles so firmly together, and which must be overcome by some superior force before we can break the solid, is spoken of as the ATTRACTION OF AGGREGATION, or ATTRACTION OF COHESION.

14. It is particularly to this form of attraction that the repulsive influence is opposed, as we see in water, which, when cooled (see note to paragraph 114), becomes ice, in which cohesion predominates, and the particles are firmly bound to each other, so as to form a solid; while the ice, when heated, again becomes water, in which the cohesive attraction is neutralised or overcome, and the particles are loosened, so as to be movable upon each other.

Application of Attraction of Cohesion as a Moving Power.

15. This force has never been used as a source of motion, except, perhaps, in the following remarkable instances, in which it was happily applied for that purpose:—The walls of a building in Paris had declined from the perpendicular, and were in danger of falling outwards, from the pressure of a heavy roof. By the following plan, suggested by M. Molard, they were restored to the upright position. A number of iron bars were stretched across the upper part of the building, passing freely through the walls. The bars were heated, in consequence of which they increased in length (57); and parts of the bars, at first within the walls, were now exterior to them. In this state the bars were *fixed* to the walls. They were then allowed to cool; when

unfit for use as a mechanical force, working through too short a distance, and not being easily procured. Attempts have lately been made, however, to render electro-magnetism efficient for this purpose.

cooled, they returned to their former size, and, being firmly fixed to the walls, necessarily pulled them inwards (towards each other); the contraction of the bars taking place gradually, but with great force. By repeating this process several times, the walls were restored to the perpendicular. Here the repulsive influence, repelling the particles of the bar, made it longer. When the bar had cooled, some power drew the particles back to their former distances. This force is considered the same as that which binds the particles of a solid so firmly together—the attraction of cohesion.

16. The same means were used to save from destruction Armagh Cathedral, in Ireland, by restoring to the perpendicular the pillars, which were considerably inclined, and on the stability of which the whole structure depended; and have been applied with success for a similar purpose in Market Weston church, in Lancashire. The wall to be restored had declined about 19 inches from the perpendicular, and weighed upwards of 200 tons. These are very interesting and striking illustrations of the application of scientific knowledge to practical purposes, and of the truth of the fine saying—*knowledge is power.*

17. Though this force is not, in ordinary cases, made use of as a moving power—by giving materials rigidity, and strength, and firmness, so as to bear pulls, strains, thrusts, and pressure of every kind without yielding, it is an essential element in giving effect to other moving powers. Cast-iron pillars, chain piers, iron cables, steam-engines, suspension-bridges, are striking instances of the power of the cohesive attraction. The great force of the cohesive attraction is well illustrated by the following table, showing the loads required to break (*i. e.* overcome the cohesion of) a prism, or cylinder, of one

square inch transverse section, of the following bodies, if suspended from them :—

	Pounds Avoirdupois.
Rope, or hempen fibres	6,400
Memel fir	9,540
Beech	12,225
Ash	14,130
Copper	19,072
Cast-iron	19,096
English malleable iron	55,872
Swedish do do.	72,064
Cast-steel	134,256

The *cohesive attraction*, and *friction* (arising from the roughness of the surfaces of bodies), are the sources of that *resistance*, without which we could not have any control over motion, or power of regulating it.

CHAPTER II.

ATTRACTION OF GRAVITATION, OR GRAVITY.

18. The peculiar feature of those cases of attraction which are classed under "gravity," is, that the substances drawn towards each other are at distances apparent to our senses; or, if in contact, yet not so near as to be within the sphere of action of the cohesive attraction. A stone falling to the ground is an example of the attraction of gravitation. It is retained there with a certain force, and cannot be lifted without applying force: the attraction between the earth and the stone is the force which retains it there. But it does not stick to the ground in the same way in which its particles adhere to each other; therefore, although, to our sense of vision, apparently in close contact with the ground, it is not so near as to be within reach of the cohesive attraction; not so close as the particles of the stone are to each other.

19. When a heavy body is suspended by a wire, its GRAVITY pulls it towards the ground; causes it to hang perpendicularly, giving it that property of downward force which we call *weight.* The cohesive attraction, binding the particles of wire firmly to each other, enables it to support the weight.

20. This attractive force is found to operate between all bodies, at whatever distances; and it acts with a force directly proportional to the mass of matter, and in inverse proportion to the square of the distance.

21. The earth being of a globular form, and so enormous a mass (7912 miles in diameter) compared with any of the bodies on its surface—*in regard to them,* the earth, though continually in motion, may be looked upon as a fixed body, drawing towards its centre, with a prodigious force, everything which rests on its surface.

22. Formerly this was the great source of motion for all sorts of machinery; and it was procured at first from the force of *running water;* a wheel, with projecting boards, being placed in a stream so as to be turned by the current. Now, however, it is usually procured from the *falling* of water, which is made to strike upon a board, or fall into a bucket, fixed to one side of a wheel. Its weight and force in falling presses the board or bucket downwards; and, by having a series of these around the wheel, a continuous circular motion is procured. The motion in the vanes of a windmill is also an example of power from the force of gravity. These methods have now been almost entirely superseded by the steam-engine; although there is reason to believe that in many situations the water-wheel * and windmill

* GREENOCK, in the west of Scotland, is most advantageously situated for the command of water power. There, instead of the

may be used with great economy. In No. 1191 of the *Mechanic's Magazine* will be found a description of BIDDLE'S PATENT EOLIAL ENGINE, a light and simple machine for using the power of wind. When steam-engines first came into use, but before the invention of Watt's double-acting engine, some of them, instead of being applied directly, as now, to work machinery, were used to raise water to turn a water-wheel, by which the machinery was impelled.

23. This source of power is not applied in the modern steam-engine; but in the first forms the engine assumed —as in the engines of Newcomen, Savery, Leopold, and even in Watt's first engine (single acting)—it was a leading element. There were two ways in which it was taken advantage of:—*First*, in causing the descent of heavy bodies, as in Newcomen's, Leopold's, and Watt's first engine; *Second*, in producing that constant force, acting on all bodies at the earth's surface, which we call atmospheric pressure.

A.—POWER FROM THE DESCENT OF HEAVY BODIES.

24. In Newcomen's, Leopold's, and Watt's first engine, this power performed the important, though secondary, office of restoring the parts to the proper situation for the exertion of the principal moving power. Indeed, the descent of a heavy body can hardly be called a *source* of

WHEEL, the long-neglected machine, called BARKER'S MILL (Whitelaw and Stirratt's patent) is beginning to be used. A new form of water-power engine, called "Hydraulic Pressure Engine," is coming into notice—in which the power of a descending column of water upon the piston of a cylinder gives motion to pumps for raising water to a different level, or produces a reciprocating motion for other purposes. It is suited for giving efficacy to waterfalls of too great height and small quantity for wheels. Two have been erected at the Alport mines in Derbyshire.—See Mr. Glyn's paper read to the British Association, August, 1848.

power (except in the case of a natural fall of water); for as much force is expended in raising the heavy body to the necessary height as is procured by its fall; so that there can be no gain of moving power.

B.—THE PRESSURE OF THE ATMOSPHERE.

25. That thin, light, attenuated, and invisible body, which surrounds the earth on every side, and which we call the air, or atmosphere, possesses the same property as other material bodies,—that of gravity or weight. Hence it exerts a downward force or pressure on every substance at the surface of the earth; and though a light body, this force is considerable, as the air extends upwards to a height of about forty-five or fifty miles.

The amount of this force has been estimated with great precision. Take a stout glass tube, closed at one extremity, and about thirty-three or thirty-four inches long, and fill it with quicksilver; then, having the open extremity closed by the thumb, a cork, or any flat plate, so as to prevent the quicksilver escaping —invert it, and place the open end under the surface of the quicksilver in a vessel containing a quantity of this liquid. Now, withdraw the substance closing the lower end of the tube; immediately the quicksilver will descend a little in the tube, leaving a vacant space at the top, and will soon become settled at a point (*a*) about *thirty inches* above the surface of the quicksilver in the lower vessel. The accompanying figure will illustrate this experiment.

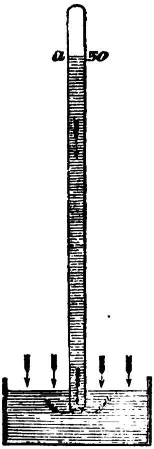

FIG. 1.

26. Here the quicksilver in the tube, contrary to the usual action of gravitation, which causes fluids communicating freely to come to the same level, remains considerably elevated above that in the lower vessel. There must be some force supporting it in that elevated situation. This power is the pressure of the air. The air is pressing on the surface of the quicksilver in the lower vessel, and thereby tending to *depress that surface*, and push the quicksilver up into the tube. There is nothing in the upper part of the tube pressing the quicksilver down; but the column of quicksilver, by its weight or force of gravity, is pressing downwards, tending to descend in the tube, to come to a level with the quicksilver below, *to raise the surface of the quicksilver in the lower vessel*, and is thus resisting the air's pressure. As these powers—the atmospheric pressure and gravity of the quicksilver—are the only forces acting, they must be equally balanced (in equilibrium) when the quicksilver has become stationary in the tube. This takes place when the column is about thirty inches high. In *figure* 1, the arrows outside of the tube represent the force and direction of the atmospheric pressure, which, from the movability of liquid particles, communicates its pressure to the liquid at the mouth of the tube, as shown by the curved arrows, evidently tending to push the liquid upwards into the tube, and resist its descent. The arrows within the tube represent the gravity of the quicksilver, acting in an opposite direction.

27. It may perhaps be remarked, that the pressure of the quicksilver in the tube is that of a narrow column only, while the air's pressure acts upon the whole of the exposed surface of the mercury below; and it may be asked, *how much of the air's pressure on the liquid in*

the lower vessel acts against the column in the tube?— The weight of air which presses on the surface of the liquid in the vessel is evidently, that of a column of air equal in transverse section to the surface of the liquid, and reaching from it to the extreme limits of the atmosphere; and of this, the portion which acts against the column of quicksilver in the tube, is *that of a column of air equal in transverse section to the orifice of the tube.* The two forces meet at that point, and may be said to be equal to columns of air and of quicksilver of the respective heights of each fluid, and equal in horizontal section to that of the orifice of the tube.

28. We thus ascertain that a column of air, reaching from the surface of the earth to the extreme limits of the atmosphere, exerts the same downwards force as (is equal in weight to) a column of quicksilver thirty inches high. And if we suppose the horizontal section of the tube to be equal to a square inch, the column of quicksilver would contain thirty cubic inches, and weigh 14·7 avoirdupois pounds.* The pressure of the air which balances the quicksilver, must be the same in amount; and, as the pressure which is transmitted to the orifice of the tube is that of a column of air the same in section, a column of air a square inch in section must weigh 14·7 pounds; and the atmosphere must press with that force on every square inch of surface. Or, every square inch is as much pressed by the air as if, supposing there were no air, a weight of 14·7 pounds rested upon it.

* The specific gravity of mercury being reckoned 13·58. But the mean pressure of the air in this country is less than 30 inches of mercury—about 29·8 inches. If this estimate were taken, it would reduce the pressure on the square inch to 14·6 lbs. Few scientific works, however, have reduced it even to 14·7 lbs.; the rougher estimate of 15 lbs. to the square inch is more usually adopted. 14·7 lbs. is a little less than $14\frac{3}{4}$ lbs.

29. The degree of pressure to which any surface is exposed from a gaseous body, is always spoken of by stating the amount of pressure on the square inch. A force double that of the air is 29·4 pounds per square inch; half that of the air, 7·35 pounds per square inch. The term "atmosphere" is sometimes employed to denote degrees of pressure—as, a pressure of "two atmospheres," meaning a pressure double that of the air—"three atmospheres," "ten atmospheres," "an atmosphere and a half," and so on. To know the total amount of pressure exerted by a gas on any body, find the number of square inches in the surface on which the gas acts, and multiply this number by the pressure on each square inch.*

30. The instrument which has just been described (25), is the common barometer, which is used to indicate variations in the pressure of the air; for its pressure varies at the same place at different times. These variations, however, are within small limits, the mercury in this country seldom rising higher than 30·8 inches, or falling lower than 28·1 inches. Its mean height, at the level of the sea, is 29·82 inches. The barometer is a useful instrument for measuring the force of confined gases or vapours, as will be seen afterwards.

31. The space between the upper surface of the mercury (*a*) and the top of the tube, *fig.* 1, is called a *vacuum* or void; meaning thereby an empty space, a space con-

* To find the number of square inches in a circular area, multiply the square of the inches in its diameter by ·7854; or, multiply half the circumference by half the diameter. The area of a circle is a little more than three-fourths, and a little less than four-fifths of the square of the diameter. Thus, if the diameter be 3 feet long, the area of the circle will be a very little more than 3-4ths of 9 square feet—about 6¾ square feet.

taining *nothing*, or, at least, none of the material bodies with which we are at present acquainted. A vacuum procured in this manner is called the *Torricellian vacuum* —(36.) It is the only perfect vacuum ; that of the air-pump and steam-engine not being quite free from elastic fluid.

32. As water is a much lighter fluid than quicksilver, it is supported in a tube much higher than the latter fluid. A column of water 33·87 feet high is required to counterbalance the pressure of the air. Accordingly, the surface of the globe is as much pressed by the air as if, in place of air, it were encircled with mercury to the height of 30 inches, or water to the height of 33·87 feet, above the level of the sea.

33. If, in the tube described, filled with water to the height of 33·87 feet, or mercury for 30 inches, an opening be made at the top, so that the air is admitted to press on the upper surface of the liquid,—as the pressure of the air communicated from outside the tube, and which supported the liquid in that elevated position, *is now balanced* by the atmospheric pressure acting *directly* upon the liquid in the tube, and pressing it in an opposite direction,—the liquid will obey the law of gravitation, and descend till it comes to the same level without and within the tube.

34. A good example of the action of atmospheric pressure is seen in the pneumatic trough of the chemist, in which, by taking advantage of this power, water is supported in jars far above the level of the water in the trough. The action of the sucker, or moistened leather with string, with which boys raise stones for amusement, depends on atmospheric pressure, which presses the leather to the stone with a force of 14·7 pounds on every

square inch. When the nozzle and valve-hole of a pair of bellows are shut, it is difficult to separate the sides, as the atmosphere presses them together with great force—(102.)

35. As air is composed of very fine particles, and exposed to great pressure at the surface of the earth, there is no situation in which it is not to be found, insinuating itself into all crevices, however minute, and rushing in on all sides, and filling up the vacant space when any body is moved. Or, if it be not itself adjoining to the vacant space, it presses the adjacent bodies into it—hence the effects of *suction*, the syringe, the common pump for raising water, &c. There are few operations going on at the earth's surface which are not, more or less, influenced by atmospheric pressure.

36. The pressure of the atmosphere was discovered in 1643 by TORRICELLI (who also invented the barometer)—the discovery being confirmed by an elegant experiment devised by the celebrated PASCAL. The air-pump—a machine for withdrawing air from a vessel containing that substance—was invented by OTTO GUERICKE, a magistrate of Magdeburg, about the year 1654. It will be explained afterwards.

Application of the Atmospheric Pressure to produce Motion.

37. As every space above the surface of the earth is filled with air, or some substance which resists and balances its pressure, it cannot be taken advantage of as a moving power until we have procured a *vacuum*, or empty space—into this the air will press with great force.

38. If we introduce under quicksilver the extremity of

a tube closed at both ends, containing no air * or other substance, and open the end under the quicksilver, the fluid will be pushed up in the tube to that height at which the gravity of the mercury will balance the pressure of the air—thirty inches ; or water (had that liquid been used) to the height of thirty-three feet. If we place a thin plate of glass, or tie a piece of bladder, air-tight, on the top of a glass cylinder open at both ends, and set the cylinder on the plate of an air-pump, with the closed end uppermost, the air, though pressing the glass plate downwards with a force of 14·7 pounds on every square inch of its surface, will nevertheless cause no motion or change, as the air in the interior resists and balances this pressure by its elasticity—(102). But if, by working the air-pump, the air be withdrawn from the interior of the cylinder, the external air will then crush the glass plate, and rush with great force into the interior of the cylinder. Or had there been, in place of the flat piece of glass, a piston fitting air-tight to the sides of the cylinder, the atmospheric pressure would have forced it gradually down, as the air was withdrawn from the interior.

39. Here is a source of motion, as shown by Otto Guericke, who attached a rope to the upper part of a piston in a cylinder, and withdrew the air from beneath the piston. The piston descended, pulling down the rope, which raised a considerable weight fixed at the other end of the rope (passed over a pulley). But *how is the air to be removed from the interior of the tube or cylinder?* this being essential before the atmospheric pressure can be applied as a moving power. The process

* The method of extracting the air from a vessel is described in par. 104.

of extracting the air by the air-pump requires force, and there would therefore be no gain of power by removing the air in that way.

40. Take a glass flask with a long neck, and, having put a little spirit of wine in it, make the liquid boil, by holding it for a short time over a fire or spirit-lamp. When the liquid is boiling briskly, having the hand protected by a thick glove, take the flask and invert it quickly, dipping the mouth under cold water. Immediately the water will be forced up with great violence into the flask; and it may even be forced out of the hand if the experiment be performed smartly, and the flask be not held very firm. In this experiment, the vapour arising from the boiling liquid gradually expels the air from the flask, the vapour then resisting the pressure of the air at the mouth of the flask. But when the flask is removed from the heat, and the vapour brought into contact with the cold water, it is rapidly condensed (returned to the liquid state). A sort of vacuum is thus formed in the flask, little resistance is offered to the entrance of any substance, and the atmospheric pressure forces the liquid up into the body of the flask.

41. Here is a *gain* of moving power from the atmospheric pressure; and this experiment is an exact representation of one part of Savery's steam-engine. Indeed, it is said that this experiment, performed by Savery with a little wine in a flask—accidentally suggested to him, from having thrown the flask on a fire, and seen the vapour issuing from its mouth—led him to the construction of his steam-engine. The same principle formed a leading feature in Newcomen's, or the atmospheric engine; the air was expelled by steam from a cylinder

having a piston working in it, and the vapour being then condensed, the piston was pressed down by the atmospheric pressure on its upper surface. Patents have lately been taken out by Carson and others for this method of procuring a vacuum, viz. driving out the air by steam—and then removing the steam—the method of removing the steam devised by WATT being employed.

42. It is this power (atmospheric pressure) that turns the vanes of the windmill; that has been proposed to be applied to the purpose of locomotion in the "atmospheric railway," and that raises the water in the common pump. Wind—the source of the moving power in the windmill—is produced by air rushing into spaces where the resistance of the air previously occupying these spaces has been diminished by the effects of heat—(101). In the common pump, the air is withdrawn from a tube dipping into the water to be raised, when the atmospheric pressure on the water exteriorly pushes it up into the tube, from which it is lifted by a piston working air-tight in the tube; and, as it ascends, fresh quantities of water rise. In the atmospheric railway the air is withdrawn from a tube on one side of a piston, while the atmospheric air is freely admitted to press on the other side—thus motion is produced in the piston, to which the carriage is attached.

SECTION II.

REPULSION.

43. ALL substances contain or have the power of producing a peculiar principle, which, applied to our bodies, excites the sensation called heat or warmth. The term "Heat" is used to express the sensation, and also the influence or substance (if it be a substance) which causes the sensation, the context showing in which sense it is applied. To express the latter solely—the something which, coming from a fire to a person near it, causes the feeling of warmth—the term CALORIC is sometimes used.

44. Caloric has the power of producing certain effects on bodies. When any substance has this power in a great degree (as a red-hot iron), it is said to be at a *high temperature*; at a *low temperature*, when in the reverse state (as a piece of ice); and the terms *rise* and *fall* of temperature, are used in a corresponding sense.

45. Caloric has the power of moving about among bodies, and always tends to an equilibrium. *Bodies at different temperatures, placed in contact or near each other, soon come to the same temperature, the warmer bodies losing heat which the colder ones gain.* The particles of heat are highly repulsive of each other, so that they fly off with rapidity from any body in which they are accumulated in considerable quantity; but they have a great attraction for the particles of all other bodies, and enter rapidly into any body deficient in

heat. This is well seen, when a hot iron, or vessel of hot water, is placed near several other bodies at lower temperatures.

46. Coldness in any body does not arise from the total absence of heat, nor from the presence of a peculiar principle of an opposite nature, but simply from its containing comparatively little heat, so that it abstracts heat rapidly from other bodies. A cold substance applied to the skin takes away heat—a warm one communicates heat.

47. Equality of temperature would soon be established over the globe, from this tendency of heat to an equilibrium, but for three causes:—*First,* The sources of heat—whether natural, as the sun's rays and subterraneous heat, or artificial, as combustion—are unequally distributed and applied: *Secondly,* While the passage of heat through bodies is not instantaneous, but requires time, they differ in the rate at which they transmit heat through them; and, *Thirdly,* Bodies differ in their powers of absorbing and giving out heat, and also in the degree in which their temperatures are affected by it.

CHAPTER I.

MANNER IN WHICH HEAT SPREADS.

Heat passes among bodies in two ways; by radiation and by conduction.

48. All bodies throw out (*radiate*) heat from their surfaces in straight lines, like radii from the centre of a circle, or rays of light from a luminous object. This mode of transmission of heat is called Radiation. The

radiated heat moves in straight lines, till it strikes on some other body, when, according to the surface on which it strikes, it is *absorbed* and warms the body, or bounds off (is *reflected*) like a ball thrown upon a wall—obeying the same laws of reflection as light and sound. In some cases, part is *transmitted*, that is, passes directly through the substance, without affecting its temperature.

49. Those bodies radiate most heat, and, of course, (other things being equal), cool soonest, whose surfaces are dark, and of a rough and porous texture. Those surfaces which are bright, of a light colour, resplendent, and highly polished—as tin-plate, polished gold, brass, or silver—radiate little heat, and hence retain their heat long. Again, those surfaces which radiate most heat, absorb the greatest quantities of radiated heat; those which radiate least, throw off (reflect) the greater part of the radiated heat which falls upon them. The following table shows the comparative powers of various surfaces in radiating and reflecting heat.

Radiating Powers.		Reflecting Powers.	
Lamp-black	100	Brass	100
Water	100	Silver	90
Writing paper	98	Tin Foil	85
Rosin	96	Block Tin	80
Sealing Wax	95	Steel	70
Crown Glass	90	Lead	60
Ice	85	Tin Foil, softened by Mercury	10
Plumbago	75	Glass	10
Tarnished Lead	45	Glass, coated with wax or oil	5
Mercury	20		
Clean Lead	19		
Iron, polished	15		
Tin Plate	12		
Gold, Silver, Copper	12		

A polished surface of silver, if the metal were warm, would lose little heat by radiation, and would throw off

the greater part of any radiant heat which might fall upon it. If covered with a coating of lamp-black (by smoking it with the soot from an oil lamp or candle), the metal would lose a great deal of its heat by radiation, and would absorb the greater part of the radiant heat which fell upon it. The application of these principles to preserve bodies warm or cool, and to the economising of heat, is obvious. The cylinder of a steam-engine should be brightly polished; that it may lose little heat by radiation. Tubes containing steam, water, or heated air, for heating apartments, should be rough, dark, and porous in the apartment where it is intended that they should give out their heat; but bright and polished before they reach that place.

50. *Second*, Heat also passes from bodies by another mode. When a poker is put in the fire, the end out of the fire soon becomes warm; this is by the transmission of heat through its substance from particle to particle. In the same way in which heat travels along the particles of one body, it can pass between two bodies in contact. The transmission of heat in this way is called CONDUCTION.

51. Bodies vary much in their power of conducting heat—some transmitting it with great celerity, while others give it a very slow passage through them. Place a rod of wood and one of iron in a fire. The end of the iron rod not in the fire will be very hot long before the similar end of the wooden rod feels sensibly warm. The following table shows the comparative conducting powers of several bodies:—

Gold	1000	Tin	303
Silver	973	Lead	179
Copper	898	Marble	23
Platinum	381	Porcelain	12
Iron	374	Brick earth	11
Zinc	363		

The powers of bodies in conducting heat appear nearly in proportion to their densities. Loose, spongy substances—as fur, straw, cotton, silk, wool, are extremely slow conductors. Bad conductors take a long time to get heated, but lose their heat slowly, and hence are useful for confining heat, or excluding heat. Good conductors get quickly heated, and cool quickly. There are many interesting applications of our knowledge of these differences in the relative conducting powers of bodies, as clothing, lining for furnaces, ice-houses, &c.

52. Liquids and gases, whose particles are loose, and move freely on each other, transmit heat through their substance in the same manner as solids—but with extreme slowness, if the heat be applied at the upper part of the fluid. But they have another and very rapid way of conveying heat, *if the heat be applied below.* The heated particles rise, cold particles from above descending and pushing them upwards; these in their turn become heated and ascend, colder particles descending; and thus a set of cold descending and warm ascending currents is established, which continue till the whole fluid comes to one temperature. Heat, entering into a fluid, causes it to become larger, and, of course, lighter; and the cold and heavier particles above necessarily descend and push the warm particles upwards. Thus the whole of the fluid is quickly heated—not by the transmission of heat from particle to particle, as in solids—but by the successive application of every part of it directly to the source of the heat. *Whenever a fluid is heated at the lower part, currents ensue.* Hence the wind—(42); hence the removal of the warm and foul air expired from the lungs of animals, and the supply of fresh air to support their respiration; hence the removal

of the noxious air formed by burning bodies, and the supply of pure air to keep up the combustion; hence ventilation—the most perfect method of which yet devised (that introduced into the House of Commons by Dr. D. B. Reid) consists in *ensuring a current* by a strong fire in a tall chimney, the room to be ventilated being in the course of the current of fresh air which rushes to the fire in the chimney, and by suitable arrangements breaking the force of the current, and enabling it to be regulated.

CHAPTER II.

EFFECTS OF HEAT.

53. When heat enters a body, it makes it larger.* It penetrates through its entire substance, and, repelling its particles from each other, their distances are increased, and the body is enlarged in bulk. This effect is termed EXPANSION. When heat leaves any body, its particles approach to each other, and its bulk is diminished—an effect termed CONTRACTION. When solids are sufficiently heated they melt, or become liquid,—a change termed LIQUEFACTION; and when liquids are heated to a great degree, they become gaseous, like steam, or the air—to which change the term VAPORISATION is applied. It is simply a very great degree of expansion, but attended by a change in form. Liquids become solid again

* There is no real exception to this general rule. Some bodies—as ice, iron, antimony, zinc, bismuth—diminish in bulk when they melt, from losing their crystalline form.

(congeal), and vapours turn liquid (condense), when they are cooled sufficiently. Heat also appears to be the cause of the ELASTIC POWER which aerial bodies possess at all temperatures, however low.

CHAPTER III.

EXPANSION.

54. THIS may be illustrated by a very simple experiment. Take a common glass flask, about half-full of water, which may be coloured, to be better seen, and invert it in a vessel of water, the open mouth of the flask being a little under the surface of the water, as seen in the adjoining cut. Then pour hot water on the flask. The heat from the water will enter the cold glass, and from it will pass to the air occupying the upper part of the flask. The air, thus heated, acquires increased elastic force, and expands (increases in bulk). Pressing on the water, it causes it to descend in the neck of the flask. If the heat be great, and the quantity of water in the flask small, the liquid will be forced entirely out of the flask, and perhaps also some bubbles of the air may be expelled. If, when the air has been expanded to any bulk, its temperature be then kept stationary, it will remain at that bulk as long as it continues of the same temperature. The same is true of liquids and solids.

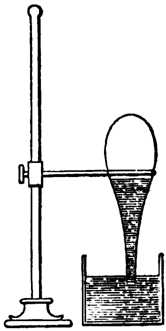

FIG. 2.

55. Here is a force or moving power procured by heating a gaseous body. This is the source of motion in an engine invented by Mr. Ericsson, which he has called the *Caloric Engine*—heated air pressing a piston in a cylinder, as in the steam-engine. This was also taken advantage of in Howard's vapour engine to increase the elastic force of the steam before it is applied to effect the motion. After leaving the boiler it is heated by contact with the flue containing the heated air from the furnace, by which a further degree of expansive force is imparted to it.

56. Take a glass tube, closed and expanded into a bulb at one end, the other being open; fill the bulb and part of the tube with spirit of wine, which may be coloured with cudbear, that the experiment may be well seen; plunge the bulb in hot water; the heat, expanding the liquid in the bulb, will cause it to press up the liquid in the stem, in which it will be seen gradually rising.

57. Take an iron rod as in (*Fig.* 3) of such length that, when cold, it will just enter between two projections at the ends of an iron bar, and of such diameter as to enter closely a circular hole in the bar. Heat the iron rod to a red heat; it will now have increased in length, so that it cannot be made to enter between the two projections; and its diameter will be enlarged, so that it is too thick to pass through the hole.

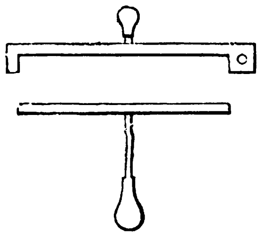

FIG. 3.

58. Had the iron rod been immoveably fixed at one

end, and a moveable body placed in contact with the other extremity, the rod, when heated, would have pushed the moveable body aside, to a distance corresponding to its own increase in length, a moving power being thus obtained. The force with which this expansion takes place, is very great, equal to the force with which it would contract on cooling—(15). Had the rod been immoveably fixed at both ends, it would have become bent, to adapt itself to its expanded condition. These effects are often seen in structures where metals are used, and particularly in iron work about fire-places, where allowances have not been made for alterations of temperature, in the bending of the bars or disjointing of the stone or brickwork to which they are fixed. In laying railway bars, allowances must be made for expansion and contraction attending alterations of temperature.

59. This enlarged condition of bodies remains while the caloric which caused it remains; when this leaves them, they return to their former size, the cohesive attraction taking greater effect in proportion as the repulsive influence is withdrawn. Plunge into cold water the heated rod, or the bulb with the liquid in its expanded state; both will return to their former dimensions—the liquid will sink in the tube, and the rod will now pass through the hole, and enter between the ends of the bar. Place the bulb of the tube, when at the ordinary temperature of the atmosphere, in a freezing mixture, which will withdraw much heat from the liquid; a contraction will ensue, as will be indicated by the sinking of the liquid in the stem.

60. In these cases, we see the opposing action of the *cohesive* and *repulsive* powers. The former was overcome to a certain extent by the heat when the bodies

were expanded, but resumed its influence, and drew the particles back to their former distances, when they were deprived of the heat which caused the expansion.

61. The heated gas also—(54), when cooled, returns to its former volume, and the liquid ascends in the flask. It is more correct to say, that, as the heat leaves the gas, the liquid, forced up by the atmospheric pressure, ascends and compresses the gas to its previous dimensions. Gases are considered to have no cohesive attraction, their particles being at such distances as to be without the sphere of this influence : *and they do not diminish in volume except from the action of some external force upon them.* This will be better understood after the perusal of Chapter IV. of this section, on the elasticity of gaseous bodies.

The Thermometer.

62. As expansion is the invariable effect of heating bodies, and a proportionate contraction ensues when they are cooled, the bulk of a body at any time is in proportion to its temperature at that time ; and we may estimate its temperature by measuring its bulk. And, as two bodies always come to the same temperature by being for a short time in contact, or near each other—(45), we may use *one* body as an instrument for taking temperatures ; having the means of measuring the bulk of this body, we know its temperature, and the temperature of any substance to which it is for a short time applied. Hence the THERMOMETER.

63. This instrument consists of a glass tube, similar to that mentioned (par. 56), but closed at the upper extremity, and having the bulb and a part of the stem filled with quicksilver or coloured spirit of wine—the

substance, the expansion, or contraction of which is to be noted. There is a graduated scale attached to the tube, by which the height (and thereby the bulk) of the liquid is indicated.

64. The bulb is applied to the body of which the temperature is required. If it be warmer than the thermometer, heat will pass to the latter, and cause expansion in the liquid ; and when they come to the same temperature, the liquid will become stationary. The bulk now occupied by the liquid indicates its temperature, that indicating the temperature of the body to which it was applied. If the body be colder than the thermometer, heat passes from it to the latter, when the liquid contracts, and sinks in the stem till they come to the same temperature. The diminished bulk of the liquid indicates its temperature, and that of the body which caused the contraction. Thus this useful instrument shows the comparative temperatures of bodies.

65. It is necessary, in speaking of different temperatures, that there be some fixed points or standards of reference, by which different degrees of temperature may be compared : so that, when any particular temperature is spoken of, it may be known precisely what is meant. Very convenient fixed points for this purpose are found in the temperature at which water freezes (or, which is the same, that of melting snow or ice), and that at which it boils.

66. If a thermometer be placed in a vessel containing a quantity of snow and water, or in the water flowing from melting snow or ice, and the height of the liquid marked, it will be found to stand at that point so long as any snow remains unmelted (if kept near the snow); and at whatever time or place the experiment be made, the

liquid in that thermometer will always stand at the same point.

67. If the same thermometer be placed in boiling water, the liquid will rise in the stem until it reaches a certain point. There it will remain as long as the thermometer is kept in the boiling water; and at whatever time or place the same experiment be performed with the same thermometer, the liquid will stand at the same point as before.* If the same experiments be performed with any other thermometer, the same uniformity of temperature will be found in these two operations—the melting of ice or snow, and boiling of water. As the thermometer, when placed in water freezing, stands at the same point as in ice or snow melting, this point is called the *freezing point;* the other is termed the *boiling point.*

68. Here, then, are two constant degrees of temperature, two fixed points, easily ascertained, and to which reference can be made for comparing different temperatures. These are now universally adopted for thermometers; and the scale of degrees is numbered in the following manner:—

69. On the scale at the side of the thermometer tube, the *freezing* and *boiling* points are marked. The distance between them is then divided into a certain number of equal parts, called "degrees." In the thermometer in general use in this country (Fahrenheit's), this space is divided into 180 degrees. To indicate higher and lower temperatures, the scale above and below these points is divided into degrees equal to those between the two

* Not strictly true. The cause and extent of the variation, which is slight under ordinary circumstances, will be explained afterwards.

fixed points. Fahrenheit imagined that the most intense cold which could be produced was when the liquid in the thermometer stood 32 degrees below the freezing point; accordingly he numbered the degrees from the supposed point of greatest cold, calling it *Zero.* Thus the number 32 is opposite to the freezing point, and 212 (180 + 32) opposite to the boiling point. 32 is familiarly known as the freezing point; 212 as the boiling point. For the numbers below zero, the sign — (minus) is used. Thus, — 10 (minus 10) signifies 10° below zero, or 42° below the freezing point.

70. In the Centigrade thermometer used in France a different division is adopted. The degrees are numbered from the freezing point, and the space between it and the boiling point is divided into 100 degrees; the boiling point being thus 100°. One degree in the Centigrade thermometer is equivalent to 1·8 or $1\frac{4}{5}$ of a degree in Fahrenheit's thermometer. In Reaumur's, used in some parts of the Continent, the distance between the freezing and boiling points is divided into 80 degrees, and the scale commences at the freezing point.

71. As the degrees are equal to each other, and an equal increase of temperature causes an equal expansion, it will cause the liquid to ascend through an equal number of degrees; and different thermometers will give the same indications with the same temperatures, however different the distances between the two fixed points and size of the degrees; for that distance is divided into the same number of degrees in all; so that, in all, the proportion of the degree to the bulk of the liquid and to the distance between the fixed points, is the same. The greater, however, the mass of matter in the thermometer to be heated or cooled, the longer time it

requires to take up the temperature of the body to which it is applied :—hence, the smaller the bulb of the thermometer is, the more quickly, and therefore the more truly, it gives the temperature of the matter to which it is applied.

72. The spirit-of-wine thermometer is used for low temperatures, as this liquid has never been frozen. It cannot be used for temperatures above 174°, as it boils at that temperature. The mercurial thermometer is used for considerably elevated temperatures, as quicksilver does not boil till 662°. It cannot be used for temperatures below—39°, as it freezes at that point, then contracting at a different rate.

Rate of Expansion in Bodies.

73. The following table exhibits the amount of expansion in different bodies, when heated from the freezing point of water (32°) to the boiling point (212°).

Elongation of Bars, Rods, or Wires.

Lead	1-351st.
Silver	1-524th.
Copper	1-581st.
Brass	1-582nd.
Gold	1-602nd.
Iron wire	1-812th.
Bar iron	1-819th.
Hard steel	1-927th.
Platinum	1-1167th.
Flint glass	1-1248th.

74. A bar of lead 351 inches long at 32°, becomes 352 inches at 212°. Besides this increase in length, it increases in breadth and thickness. To find the total expansion (roughly), place 3 as the numerator of the above fractions, or, retaining the same numerator, divide the denominator by 3 : correctly, the expansion in size

is in the ratio of the cubes of any side expanded and unexpanded.

75. The expansion of the following liquids, heated through the same range (32° to 212°), is seen below. The expansion in bulk, or total expansion, is stated. The two first are taken from different points ; as spirit of wine boils at 174°, and oil freezes at about 36°.

Spirit of wine (—8° to 174°) . . .	1-9th.
Whale oil (60° to 212°)	1-11th.
Oil of turpentine	1-14th.
Water	1-22nd.
Quicksilver	1-55th.

76. All gases and vapours expand equally through the same range of temperature. Their expansion is very great. 1000 volumes of any gas at 32°, become 1375 volumes at 212°—expanding 3-8ths ; or 1-480th for every rise in temperature of one degree of Fahrenheit.

77. Thus, in expanding bodies, heat produces the least effect upon solids, a greater effect on liquids, and has a still greater expansive power in gases. Also, while all gases undergo the *same expansion* from an equal increase of temperature, it is very different with solids and liquids ; the same rise in temperature causes *different degrees of expansion* in different solids and liquids.

78. The reasons for these peculiarities, are, the differences in the strength of the cohesive attraction in solids and in liquids, and the absence of it in gases. In expanding solids, heat is resisted by the cohesive force, which is strong in them—hence it produces a small effect. The particles of liquids are less firmly bound by cohesion, and the same increase of heat, having less cohesion to overcome, produces a greater expanding

effect than in solids. The cohesive force appears to be entirely suspended in gases; heat is not resisted in its expanding power, and a great increase in bulk is produced by a small rise in temperature. The cohesive force being different in solids, and also among liquids, each opposes a different degree of force to the efforts of heat to expand them. Hence the unequal expansion of solids and of liquids through the same range of temperature. In gases, where this force is absent, the same increase of heat produces the same expansion in all.

CHAPTER IV.

OF THE ELASTICITY OF GASEOUS BODIES.

79. We have seen that the expansion of gases, when heated, is a source of moving power. *But gases in their ordinary state, at all times, exert a force or pressure on the surrounding bodies.* Every gas or vapour contains within itself a source of expansion, and hence of moving power, which is prevented from acting and producing motion, only by some other force which compresses the gas, and thus resists its action. It is similar in its nature to a compressed or wound-up spring. Its particles are constantly pressing outwards on each other, and upon the bodies around them, *and the gas is continually endeavouring to swell out in all directions, and occupy a larger space.* This power of gaseous bodies is termed their *elasticity, elastic power, or elastic force.*

80. This remarkable property of gases, which is peculiar to them—liquids and solids not possessing any such power—arises from the distances of their particles,

which are thus without the sphere of the cohesive attraction, so that no resistance is offered to the repulsive power of the great quantity of heat they contain, which is constantly exerting upon them its usual action—that of repelling their particles asunder. Hence, the consideration of this elastic power of gases has been placed beside the other phenomena of heat.

81. Place a rather flaccid bladder in the receiver of an air-pump, and withdraw the air from the interior of the receiver; the air in the bladder will expand in proportion as the pressure upon it (from the surrounding air in the receiver) is diminished by the withdrawing of the air; the bladder will swell, become full and distended, and even be burst by the expansion of the contained air, if the vacuum be very complete, or the bladder have been nearly full of air.

82. In the adjoining figure (*Fig.* 4.), showing the section of a cylinder, with a piston moving freely but air-tight, if the space in the cylinder below the piston were filled with lead, or iron, or any other solid, and the piston were raised, the solid would remain in exactly the same situation as before, being retained by the force of gravity and the cohesion of its particles; and the space between the solid and the piston would be a vacuum. With a liquid in the place of the solid, the same would take place; the liquid would remain if the piston were raised.*

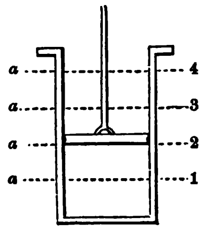

FIG. 4.

* A little vapour would rise from volatile liquids, as ether, spirit of wine, water, and be diffused through the space between the piston and the surface of the liquid; but the mass of the liquid would remain in its previous situation.

83. But if the space below the piston had been occupied by any gas or vapour, then, on elevating the piston, *the gaseous body would follow it ; there would be no vacuum ; the gas would expand and be equally diffused through the whole space between the lower surface of the piston and the bottom of the cylinder.*

84. This elastic force of gaseous bodies is resisted by the pressure to which they are exposed ; and, therefore, these forces must be equal to each other in any gas which is in a quiescent state. Thus, in an apparatus such as *Fig.* 4. represents, if the piston be at rest at some distance from the bottom, it is clear that the gas confined below the piston is pressing it upwards (the resistance from friction being disregarded) with a force exactly equal to that with which the piston tends downwards from its own weight, and that of any bodies resting upon it. In *Fig.* 4. if the piston be at rest in the situation *a* 2, and the force with which it tends to descend be equal to a weight of ten pounds, then the force with which the gas below presses upwards on the piston, is also equal to a weight of ten pounds. Hence, then, *the elastic force of a gas is exactly equal to the force by which it is confined.*

85. If the piston have now additional weights equal to ten pounds laid upon it, it will descend till the gas occupies only half the space through which it was at first extended ; then (at *a* 1) it will remain at rest. Here, while the same quantity of gas is diminished in bulk to one-half, the force with which it presses the piston upwards is doubled, for it now supports a weight of twenty pounds. But when a given quantity of a gas is *diminished in bulk, its density or specific gravity is increased.* In this case, the density has been doubled,

at the same time that it supports a double force. Hence, then, *the elastic force of a gas is in direct proportion to its density, and inverse proportion to its bulk*—that is, its elastic force increases in the same proportion in which its density is increased, or its bulk diminished.

86. This important general proposition might also be illustrated in the following ways.

87. If five pounds had been taken off the piston while at rest in the situation *a* 2, it would be forced up by the elasticity of the gas to the situation *a* 4. Here, while the volume of the gas is doubled, its density and elastic force are diminished to one-half, for it is now diffused through twice the space, and supports only half the weight.

88. If one half of the gas had been withdrawn while the piston was in the position *a* 2 and its weight equal to ten pounds; the density of the gas being thereby reduced one-half, its elastic force would be reduced in the same proportion, and the piston would descend to *a* 1. In this situation, the density of the gas is now the same as before any was withdrawn, and the force it now exerts against the piston is also the same.

89. If, instead of withdrawing gas, a quantity were forced in equal to what was there before, the piston (still loaded to the amount of ten pounds) would be forced up to the situation *a* 4. Twice the quantity of gas being diffused through twice the space, its density remains the same, and therefore its elastic force is also the same, or equal to a force of ten pounds pressing the piston upwards.

90. If, when this additional quantity of gas was forced in, the piston were loaded with an additional weight of ten pounds, it would have remained at *a* 2.

The density of the gas being double, its elastic force is double, and it resists a double compressing force.

91. In all these cases, we have supposed the pressure downwards on the piston to be entirely within our control, and disregarded the atmospheric pressure, which would constantly press the piston downwards, with a force equal to a weight of 14·7 pounds on every square inch of its surface. For performing the experiment, the atmospheric pressure might be neutralised by a counterpoise, attached to the piston by a cord passing over a pulley.

92. The following table will illustrate this general law of the constitution of gaseous bodies. Let the volume and elastic force of any given quantity of a gaseous body be represented each by the number 1, while the density is 1. With alterations of the density, the following will be the corresponding alterations of the volume and elastic force.

Density.	Volume.	Elastic Force.
1	1	1
2	$\frac{1}{2}$	2
3	$\frac{1}{3}$	3
10	$\frac{1}{10}$	10
$\frac{1}{2}$	2	$\frac{1}{2}$
$\frac{1}{4}$	4	$\frac{1}{4}$

This relation between the density and elasticity of aërial bodies, is known by the name of "the law of Marriotte," that philosopher having pointed it out. Till lately, it was supposed not to apply in high pressures; but, from the experiments of Oersted, it was found to hold with pressures so great as 110 atmospheres, and is probably universal.

93. It is to be understood as a condition in the preceding experiments, that the temperature is the same in

all. Any increase in temperature increases the elastic force (54), while this is diminished in a corresponding degree by a reduction of temperature. In any gaseous body, temperature and density remaining the same, the elastic force is also the same; and any change in either determines a corresponding change in the elastic force.

94. As gaseous bodies are thus capable of being drawn out by relieving them from pressure, and compressed by increasing the pressure, they are frequently termed *elastic fluids*, in opposition to liquids, which possess this property in a very slight degree. Water was for a long time supposed to be quite incompressible—it is almost so; its diminution in volume being only 51·3 millionths (about 1-20,000th) for every atmosphere of pressure, as determined by the experiments of Oersted and others.

95. It must be observed that this elastic force of a gas is totally different from its weight or gravity, and in effect much greater. A hundred cubic inches of air weigh only 31·0117 grains: * a column of atmosphere of one square inch transverse section, has only a weight (downwards force) of 14·7 pounds. The pressure from its weight is thus small; but its elasticity is comparatively very great, as may be easily illustrated.—The atmospheric pressure would force 14·7 pounds of mercury (30 cubic inches) into a tube of *one square inch transverse section* from which the air had been previously exhausted, on opening it under mercury (38). But if the tube were full of air, and the open end then plunged under the surface of the mercury, not a particle would enter, if the tube were held quite vertically. *Now,*

* About $31\frac{1}{100}$ grains: avoirdupois weight, 7000 grains in the pound.

supposing the tube to be about 30 *inches high, about* 10 *grains weight of air would fill it, completely resist this atmospheric pressure, and prevent the mercury from entering.* It cannot be the weight of this small quantity of air which resists a force of 14·7 pounds, about 10,000 times its own weight—it must be some other power, so that here the elastic force of this trifling quantity of air balances the force produced by the weight of a whole column of atmosphere of the same transverse section.

96. In like manner, any quantity of air, however minute, introduced into the space above the mercury in the barometer tube, would, by its elasticity, exert a certain influence in resisting the atmospheric pressure, and depress the liquid in the tube. Hence an important application of the barometer. If the space above the mercury in a barometer tube communicate with a vessel containing any gaseous body, we can ascertain the elastic force of that body. It will depress the mercury in the tube, and, by noting the difference between the height of the mercury in this tube, and its height in another having no gaseous fluid above the mercury (the common barometer), this difference will express the elastic power of the gas pressing on the upper surface of the mercury. For every inch of difference we may allow 0·49 pounds (3430 grains, or about half a pound,) of pressure on the square inch to the gas which depresses the quicksilver. Thus, if the difference be four inches, the elastic force of the gas is 1·96 pounds on the square inch. In this manner the barometer is used in the common air-pump, and in the condenser of the steam-engine.

97. On the other hand, if the gas be of an elastic force greater than the atmospheric pressure, the barometer is made in the form of a U, one end communicating with

the gas, the elasticity of which is to be measured, the other being open, and of course exposed to the atmospheric pressure. When the elastic force of the gas is exactly equal to the atmospheric pressure, the mercury will be at the same height in both limbs of the tube ; and when the elasticity of the gas exceeds the atmospheric pressure, the mercury will be depressed in the limb communicating with the gas and raised in the other. The difference in level of the mercury in the two limbs, will express the *excess of the elastic power of the gas over the atmospheric pressure.* If the tube be closed, the mercury will stand about 30 inches higher, and then the difference in level of the mercury in the two limbs will express the whole force of the gas.—There are thus three forms of expression for the force of steam or any aërial body—atmospheres—pounds pressure on the square inch of surface—height of column of mercury which it would support in inches. The relation between these will be readily understood from the following table :—

Atmospheres.	lbs. on square inch.	Height of Mercury.
½	7·35	15 inches.
1	14·7	30 „
1½	22·05	45 „
2	29·4	60 „
3	44·1	90 „

98. As the air at the surface bears the compression of a force of 14·7 pounds on every square inch, its elastic force must be exactly equal to the compressing power, 14·7 avoirdupois pounds on every square inch of surface ; on every side, above, and below, as this elastic power knows no distinction of up and down. This pressure is frequently, in round numbers, termed 15 pounds. For small quantities the difference is not important ; but it

makes a considerable difference on high pressures. The true number is 14·6 pounds.

Gaseous Elasticity as a Moving Power.

99. Let us suppose a cylinder with a movable partition in the middle, and filled with air or any other gaseous fluid. Let this partition be light, fitting closely to the sides, so that no gas can pass from one side of the partition to the other, and at the same time capable of free motion within the cylinder. Now, if there be equal quantities of the same gas on each side of the partition, and the different portions be at the same temperature, the partition, being equally pressed on each side, will remain exactly in the middle. If, in this state of things, some of the gas be withdrawn from one cavity, the density of the gas remaining in that cavity being thereby reduced, its elastic force will be less; and the gas on the other side, now being less resisted, its particles will obey the impulse of their elasticity, motion will take place, and the partition will be pressed towards that side from which the gas was withdrawn.

100. Here is a moving power gained by withdrawing some of a gas pressing on one side of a body, while there is a quantity of confined gas on the other side. Power procured in this manner is used in those of Watt's engines, called "expansion engines," with the view of economising the steam: and this system is coming daily more and more into use for all kinds of steam-engines.

101. The same effect would take place, were the gas in one cavity reduced in temperature, or the temperature of the other portion raised. Thus a confined gas may be made a source of moving power in two ways:—*First,* by increasing its temperature; *Second,* by removing

some of the pressure by which it is confined. And the latter may be done in two ways, when the pressure arises from a gaseous body:—*First,* Reducing its temperature; *Second,* Withdrawing some of the gas. When the gaseous body to be withdrawn is a vapour, this may be done in the way described in paragraph 40, called condensation, which will shortly be explained more fully.

102. Knowing that the air possesses *elasticity* as well as *weight,* we can understand many phenomena otherwise inexplicable. Hollow vessels containing air (38) support the enormous pressure of the external air, by the elasticity of the air within. Were not air or some other elastic fluid within, their sides would be crushed together; and we shall see that, in the boiler of the steam-engine, it is necessary to have a particular contrivance to prevent this occurring. When we attempt to separate or press together the boards of the bellows (34), the nozzle and valve-hole being shut, the *elasticity of the air within* tending to separate the boards, *and the pressure of the exterior air* tending to force them together, are equal at first; but, when we press them together, or separate them, the elasticity of the air within the bellows is increased in the first case, diminished in the second, and force is required to keep them in either state. In the case of the sucker with which boys raise great weights (34), if the moistened leather be properly applied, there is no air between the leather and the stone, so that the atmospheric pressure is not resisted in its pressure on the leather.

103. The elastic power of air is taken advantage of in many machines—as Hero's fountain, the hydraulic ram, the air-vessel for producing a continuous stream in the force pump and bellows for blast furnaces, the air-

gun, common lifting pump, condensing syringe, and air pump. The compression of air has been proposed as a means for procuring a *portable power.* A large quantity of air is pumped into a small stout vessel, and let out by a stop-cock as it is required. See in No. 1179, vol. xliv. "Mechanic's Magazine," a description of a compressed air engine, and its application to locomotion. Air is compressed by powerful engines at fixed stations: and a vessel of it supplied to each locomotive as it comes up, to be let out for propelling it to the next station.

The Air Pump.

104. The air pump is a very important part of Watt's engine—indeed of all condensing engines. This machine is a contrivance for extracting the air from a vessel,—a more difficult operation than might at first be supposed. Its action depends on the elastic property of the air to be removed. It will be understood from the annexed figure (5), and description. Let *d* be the vessel to be exhausted of air. Let it be connected with a cylinder having a valve *c* opening upwards, and a piston *a b* with one valve (or two) also opening upwards. Let the vessel *d* and the cylinder contain air of the usual elasticity, and the piston be near the top of the cylinder. Now press down the piston—the air in the cylinder being thus condensed, will press and keep shut the lower valve *c*, and, when it has sufficient elastic force, will press open the valve in the piston and escape. Let the piston be pushed

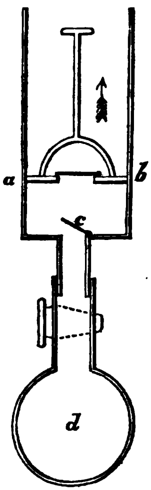

FIG. 5.

to the bottom of the cylinder—all the air it contained will thus be expelled. Now raise the piston to the top of the cylinder: in the figure the piston is represented ascending. Whenever the piston is raised, there will be a vacuum between it and the valve *c*, and therefore no pressure on the upper surface of that valve; the air in *d* will therefore force it open and rush into the cylinder, and when the piston is at the top *the air formerly in* d *will be diffused through* d *and the cylinder*. Thus a quantity of air has been removed from *d*, and, from the construction of the valve *c*, it cannot return. Also, no air can enter the cylinder from without, as the piston-valve is kept shut by the atmospheric pressure, a much greater force than that of the now rarefied air pressing on the lower surface of the piston valve. Push down and raise the piston as before, and repeat this often. The air in the cylinder will be expelled as before, and the remaining air in *d* will divide itself between *d* and the cylinder, and so on—no air ever entering into *d*, as the valve *c* opens outwards. This may be continued until the elasticity of the air in *d* is so weak as to be unable to push up the valve *c*. Hence, in some air-pumps, there are contrivances for lifting the valves by the power that works the pump; and in others the air is withdrawn without the aid of valves. The above, however, is the plan adopted in the steam-engine.—By reversing the valves in *fig.* 5, so that they open *downwards*, we would have a *condensing syringe* for forcing air into a vessel, such as would be used for the compressed air-engine alluded to in par. 103, or for the air-gun.

CHAPTER V.

VAPORISATION.

105. It is an invariable effect of heat, then, to enlarge the dimensions of any body into which it enters. But this enlargement, in ordinary cases, is not great; gases, which expand most, must be heated through a range of about 480° Fahrenheit before their bulk be doubled.

106. There is one case, however, in which heat does produce a very great increase of bulk—*when it causes a liquid to pass to the gaseous or aërial state;* as when water boils (becomes steam). Here there is not only expansion, far greater in amount than in the former cases—there is also a change in the form or condition of the body; it is now an elastic fluid—(94), light, eluding the sense of touch, and in most cases invisible.

This change is called VAPORISATION, and the elastic fluid into which the liquid is converted is called a VAPOUR.

A.—VAPORISATION AS A MOVING POWER.

107. Take a flask, such as that represented in *fig.* 2, and pour coloured water into it till it is almost full, leaving room for a tea-spoon-full of ether, which is to be added; then, closing the mouth of the flask, invert it, make the mouth dip under water, remove the substance closing the mouth, and get it properly supported in that position. The ether, being a light liquid, and not mixing

with water, will ascend to the upper end of the flask, resting on the surface of the water. Now, pour boiling water on the flask: almost instantaneously the ether will expand enormously, become a gaseous body, transparent and colourless, press down the water, and occupy a large part of the flask.

108. Here is a force or moving power obtained by the conversion of a small bulk of liquid into a vapour occupying a far greater space. This experiment illustrates the methods which De Caus and Lord Worcester proposed as a means of raising water, and the power used in modern steam-engines; and it is an exact representation of one part of Savery's engine.

109. Most gaseous bodies are colourless and invisible: but chlorine has a pale yellowish-green colour, and the vapour of iodine is of a fine violet hue. That the vapour of water is invisible may be seen by boiling a little water in a glass flask. The vapour between the surface of the liquid and mouth of the flask is clear, transparent, and colourless: it is only after it is fairly out of the flask, and is cooled and partly condensed by the cold air, that it assumes an opaque and white or grey appearance, like a cloud.

110. This phenomenon takes place with almost all liquids, when they are sufficiently heated; but at different temperatures, each having a boiling point peculiar to itself. Also they expand differently when vaporised. The following table shows the boiling points of several liquids; the bulk of the vapours into which they expand; and the specific gravities of these vapours—that of air at 212° being 1.

The expansion of water is very nearly one cubic inch into one cubic foot (1728 times its former bulk).

	Boiling Point.	Bulk of Vapour.	Specific Gravity, air at. 212°=1.
Water . . .	212°	1696*.	0·623
Spirit of Wine . .	174°	493	1·633
Sulphuric Ether . .	96°	212	2·586
Oil of Turpentine .	316°	192	5·013

111. Vapour rises from most liquids at all ordinary temperatures, even at temperatures far below their usual boiling points ; but it comes from the surface only, when the temperature is below the boiling point of the liquid.

112. The temperature of the vapour is the same as that of the liquid from which it arises, as may be easily seen, by holding a thermometer in boiling water, and then in the steam arising from it.

113. Vapour is raised, and sustained in that state, solely by the influence of heat, not at all by the attraction of the air, as was at one time supposed ; and the quantity of vapour which can exist in any given space bears a certain proportion to the temperature—(129, &c.).

B.—RETURN OF VAPOURS TO THE LIQUID STATE.

114. Vapours, when the heat which caused them to be in that state is withdrawn, return to their former bulk (the bulk of the liquid from which they were raised), and to the liquid condition. This phenomenon is called *condensation.* It is seen when steam, issuing from a boiler, strikes on any cold surface. The steam is condensed, and returns to the state of water, appearing in small globules. The heat being withdrawn by the cold body,

* The estimate of the increase in bulk is calculated from the greatest density of water, which is at 39·39 Fahrenheit.

the cohesive attraction resumes its influence, draws and retains the particles in contact, so as to form water.*

115. The colourless nature of steam, its formation, and condensation, are well shown by a beautiful apparatus devised by Dr. Wollaston. The annexed figure illustrates it. A glass tube is formed into a bulb at one end, and has a piston within, which, with its rod, is perforated. There is a screw at the top of the piston-rod, by which the aperture in the piston-rod may be opened or shut at pleasure. A little water being introduced into the bulb, it is made to boil, and, when the air has been expelled, the opening in the piston is shut. Then, if the heat be continued, and more steam formed, it will raise the piston. On allowing the tube to cool, the steam will be condensed, and the piston will be depressed by the atmospheric pressure. It will be seen that the steam, unmixed with air, is perfectly clear, transparent, and colourless.

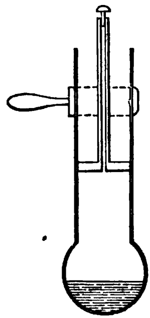

FIG. 6.

* Thus there are two great antagonistic powers operating between the particles of matter: the influence of heat, or repulsion, tending to separate them and to make bodies occupy a large space; the attraction of cohesion, tending to draw the particles of bodies closer and closer to each other, and to reduce them in bulk. When there is little of the repulsive principle present, as in ice, the attractive principle operates powerfully, and the particles are firmly bound together in the form of a solid. When the ice is heated, the heat, to a certain extent, overcomes the cohesive attraction, and the particles are loosened and become movable on each other, as in water; and, when a large additional quantity of heat is infused, the cohesive principle is overcome, and, the repulsive principle being predominant, the particles are driven far asunder, in the form of steam. Reverse these operations, and we have the steam successively passing to the state of water and ice.

116. The prodigious expansion of water when vaporised (a cubic inch to a cubic foot), the great reduction in bulk when condensed (a cubic foot to a cubic inch), and the ease with which steam is condensed, are the properties which render water so valuable as a means of procuring force or moving power.

C.—INFLUENCE OF PRESSURE ON VAPORISATION.

117. We have seen that pressure resists the endeavours of gases to expand—(84, &c.); in like manner, pressure upon the surface of any liquid opposes the expansion of its particles into the gaseous state, and, in proportion as the pressure is great, a higher temperature is required to overcome it, and cause part of the liquid to expand into vapour.

118. When a liquid is exposed to heat in a confined space, from which the vapour that rises cannot escape, this vapour, by its elastic power—(79), will press upon the surface of the liquid, and oppose the further vaporisation of the liquid. If the heat be increased, this force will be overcome, and an additional quantity of vapour will be added to that already pressing upon the surface of the liquid. The density of the vapour being thus increased, as well as its temperature—(93, 101), its elastic force is further increased, and it now resists with still greater force the passage of any of the liquid into the aëriform condition. There is thus a struggle between the heat, which tends to repel the particles of the liquid asunder, in the form of vapour, and the pressure, which tends to confine these particles in a small space. When the vapour that rises is not confined, the temperature remains at the usual boiling point, as the steam that rises carries off the

heat as fast as it is infused into the liquid—but when the vapour is not permitted to escape, the heat added remains in the liquid and in the vapour above it, and raises their temperature.

119. Thus, by exposing a liquid to heat, in a confined vessel, we may procure a vapour of any density, and, hence, of *any degree of elastic force*, compatible with the strength and power of sustaining heat of the vessel, on the interior of which it thus exerts what is called a BURSTING PRESSURE.

120. Hence, liquids vary in their boiling points with the pressure to which they are exposed. In elevated situations, (as the tops of high mountains, the cities of Quito and Mexico, where the pressure of the atmosphere is less—less by the amount of atmosphere beneath the elevation,) water boils at lower temperatures than on low plains, where subjected to the pressure of the whole atmosphere. A change of one degree of Fahrenheit in the boiling point of water indicates a change in elevation of 530 feet. Or, a variation of 1·76° Fahrenheit, in the boiling point of water, takes place with a change of one inch in the height of the barometer, between the limits of 26 and 31 inches. In the vacuum of an air-pump, liquids boil at about 140° Fahrenheit lower than when exposed to the ordinary atmospheric pressure.

121. At Quito, 9542 feet above the level of the sea, water boils at 194° Fahrenheit. At Geneva, about 1200 feet above the level of the sea, water boils at 209·4° Fahrenheit.

122. In the *Digester*, on the other hand, which is merely a stout metallic vessel (copper), like a boiler, with a fixed lid and a stopcock attached to the tube for

emitting the steam; by confining the vapour we may retard the boiling of water, and raise it to any temperature compatible with the capacity of the vessel to bear pressure, and the action of the high temperature necessary to produce steam of such elastic power. In this manner, substances can be exposed to higher temperatures than can be procured by boiling water in an open vessel. In elevated situations—such as Quito or Geneva—the same temperatures cannot be procured by boiling water or other liquids in open vessels, as in lower situations.

D.—OF THE FORCE OF STEAM.

123. In considering the elastic force of steam, it must be recollected that, the temperature remaining the same, the *density* and *elastic force* of a gaseous body are in direct proportion; and that an increase of either temperature or density increases the elastic force—(93, 101).

124. *The elastic force of a vapour rising from a boiling liquid is always exactly equal to the pressure which resists its passage to the gaseous state*—(117), or, as it is usually expressed, *equal to the pressure under which it is raised.* In fact, a liquid does not boil until it has sufficient elastic force to balance and overcome this pressure.

125. There is a constant force—the atmospheric pressure—resisting the expansion of liquids into vapours; hence the elastic force of any vapour produced from a liquid boiling in an open vessel while the barometer is at thirty inches, is 14·7 pounds to the square inch, and varies with the height of the barometer (the index to

variations in atmospheric pressure), the boiling point varying also, as the following table illustrates—

Barom. in inches.	Boiling Point of Water.	Elasticity in pounds on the square inch.
28	208·43	13·72
29	210·19	14·21
30	212	14·7
31	213·76	15·19

126. The following more extended table will illustrate better the condition of watery vapour at different temperatures, the proportion between the temperature and density, and the correspondence between these two and the elastic force or pressure. The manner in which the elastic force of a vapour is ascertained may be judged of by referring to paragraphs 96 and 97.

Temperature, Fahrenheit.	Specific Gravity, air at 60° being 1.*	Weight in Grains of a Cubic Foot.*	Pressure in inches of a column of Mercury.	Pressure, in pounds on the square inch.
Degrees.				
60·00	0·0115	6·10	0·55	0·2695
77·00	0·0202	10·70	1·00	0·49
98·70	0·0388	20·50	2·00	0·98
123·00	0·0744	39·00	4·00	1·96
147·60	0·134	71·00	7·50	3·675
178·00	0·255	135·00	15·00	7·35
197·40	0·371	196·	22·50	11·025
212·00	0·484	254·7	30·00	14·7
220·00	0·443	292·0	35·00	17·15
233·80	0·687	363·0	45·00	22·05
242·50	0·81	427·0	52·50	25·725
250·20	0·915	483·0	60·00	29·4
274·70	1·33	700·0	90·00	44·1
320·60	2·5	1317·0	180·00	88·2
350·00	3·61	1910·0	270·00	132·3
450·00	10·75	5670·0	900·00	441·0

* The weight of a cubic foot of air at 60° F., 30 Barom., is 535·8821 grains; 100 cubic inches weigh 31·0117 grains. A cubic foot of air at 212° F., 30 Barom., weighs 413·6832 grains; and if the specific gra-

The following table is the result of an inquiry instituted by the Academy of Sciences at Paris, in which Arago and Dulong were engaged. Up to the pressure of twenty-five atmospheres, the table gives the results of actual experiments. The temperatures and corresponding pressures above that were obtained by calculation. The first column shows the force of the steam, expressed in atmospheres ; and, in the second column, the figures express the corresponding temperature in degrees of Fahrenheit. Thus, steam formed at 263·84 has an elastic force of 2½ atmospheres ; or, a pressure on the square inch of 36·75 pounds = 14·7 lbs. × 2½.

Elasticity in Atmospheres.	Temperature.	Elasticity in Atmospheres.	Temperature.	Elasticity in Atmospheres.	Temperature.
1	212·	7½	336·86	20	418·46
1½	233·96	8	341·96	22	427·28
2	250·52	9	350·78	24	435·56
2½	263·84	10	358·88	25	439·34
3	275·18	11	366·85	26	443·16
3½	285·08	12	374·00	28	450·38
4	293·72	13	380·66	30	457·16
4½	300·28	14	386·94	32	463·64
5	307·5	15	392·86	34	469·78
5½	314·24	16	398·48	36	475·64
6	320·36	17	403·82	38	481·24
6½	326·26	18	408·92	40	486·59
7	331·70	19	413·78	45	499·14
				50	510·60

127. From these tables, it appears that, if a quantity of water were heated to 320° Fahrenheit by confining the

vity of air at 212° be termed 1·000, that of steam formed at 212° is 0·624. There are about 13 cubic feet of air in a pound of this body at 60° (avoirdupois weight).

vapour, a cubic foot of the vapour at that temperature would weigh 1317 grains (about three ounces avoirdupois); its specific gravity, compared to air at 60° as 1, would be 2·5, weighing, therefore, two and a half times as much as an equal bulk of air; if communicating with a closed tube, like a U, containing mercury, it would support a column of that fluid metal 180 inches (fifteen feet) high; or 150 inches if the tube were open, the atmospheric pressure being equivalent to thirty inches of the column; and it would exert on every square inch of surface of the vessel containing it, a pressure equal to that of a weight of 88·2 pounds avoirdupois—*i. e.*, a pressure of six atmospheres.

128. This table might be continued downwards—as, at lower temperatures still, vapour can be sustained; of diminished density and elastic force, but never losing elastic power while it retains the form of vapour. At 32° Fahrenheit, according to Dalton, watery vapour will have an elastic force equal to 0·2 inch of mercury (·098 lbs. —nearly one-tenth of a pound of pressure on the square inch); and a cubic foot of such vapour weighs 2·3701 grains. At 50° Fahrenheit, the force of vapour, according to the same author, is 0·375 inches of mercury (·183 of a pound pressure on the square inch); and a cubic foot of such vapour weighs 4·2819 grains.

129. Any given space, then, can contain only a certain quantity of vapour at a certain temperature; the vapour is sustained in that state solely by the influence of heat; and its quantity bears a constant proportion (which has been determined by experiment) to the temperature.

130. Hence, if a quantity of vapour, in a confined space, be reduced in temperature, the space having contained as much vapour as it could at the previous

temperature (being *saturated* with vapour), a certain quantity of vapour will now return to the liquid state, and *the remainder will expand and be spread through the whole of the space—much reduced, however, in density and elastic force*; tables such as that in paragraph 126, show how much. For example, if a cubic foot of steam, at 212° Fahrenheit, and of elastic force of 14·7 pounds to the square inch, being of the specific gravity 0·484—*i. e.*, 254·7 grains of steam (all that can be sustained in vapour at that temperature in such a space)—be reduced in temperature to 60° Fahrenheit; 248·6 grains will return to the liquid state, and 6·1 grains will remain in a state of vapour, diffused through the entire cubic foot, having a specific gravity of 0·0115, and an elastic force of 0·2695 pounds (about a quarter of a pound) on the square inch.

131. Thus the condensation of vapour by cold can never produce an absolute vacuum—some vapour will remain, though of greatly diminished elasticity. This vapour will be rare, and of weak elastic force, just in proportion to the intensity of the cold employed to reduce the rest to the liquid state. This must be kept in mind in studying the steam-engine, and also for understanding the history of its progress from the first rude attempts to its present more perfect form.

132. From these tables, then, it will be seen that vapour rises from water at all temperatures; that its density increases with the temperature, and its elastic force with the density.

133. Steam of the same elastic force as the atmospheric pressure is called *low-pressure steam*, no pressure above that of the atmosphere being required to produce it. To produce steam of greater elastic force than that

of the air, a close vessel must be used, the lid being kept down by weights proportioned to the strength of steam required. To procure steam having twice the elastic pressure of the air, we must confine it by twice the force, or 29·4 pounds to the square inch. The atmospheric pressure furnishes 14·7 pounds of pressure (a pressure of *one atmosphere*, as it is termed); and, to provide the other atmosphere of pressure, we must lay such weights on the lid of the vessel, that there are 14·7 pounds for every square inch of the opening which admits the lid. In this manner, we procure steam of any required pressure greater than the atmospheric pressure, and it is called *high-pressure steam.* Steam of only a few pounds' (five or six) pressure higher than that of the atmosphere is still usually termed *low-pressure steam.*

134. In the preceding paragraphs, we have spoken of steam when in contact with its water of generation. In this condition, it obeys a different rate of decrease or increase in its elastic force from that of steam cut off from communication with water. In the first case, when the vessel is heated, the elastic force of the steam is increased by two causes:—*First,* by the increase of heat; *second,* by the increase in density from the addition of more steam, and *vice versâ,* when the temperature is diminished. But, when not in contact with any water to generate more steam, addition of heat increases its elastic force from the increased temperature only, no increase of density taking place.

135. When water contains saline matters in solution, its boiling point is raised, though the external pressure, and consequently the force of the vapour, be the same. Sea-water, containing $\frac{1}{33}$ of saline matter, boils at 213·2°, the barometer being at 30 inches. Water containing $\frac{7}{33}$

of salt boils at 220°; while water saturated with salt, *i. e.* containing 12-33ds of salt, boils at 226°.

136. Thus, the conditions, liquid and gaseous, do not seem to be absolute and essential to the constitution of any body, but relative to and depending on the temperature; so that it is likely that all liquids might be vaporised, even liquid metals, could we procure temperatures sufficiently high; and that all aërial bodies might be condensed, by simply abstracting heat from them, could we procure temperatures considerably lower than we can at present command. There are some bodies which are known to exist only in the gaseous state: such are oxygen, hydrogen, nitrogen, and a few others. These, which cannot be reduced to the liquid state by a reduction of temperature, are called *gases;* while the aërial bodies which are formed by the influence of heat upon liquids, and which return to the liquid state when they are cooled, are exclusively called *vapours.*

137. Some aërial bodies, which cannot be rendered liquid by the mere abstraction of heat, have yet been reduced to the liquid state by pressure, or by pressure and cold combined. As pressure retards the passage of a liquid to the aërial state, so it tends to reduce an aërial body to the liquid condition. The particles are thus approximated, and brought within the sphere of action of the cohesive attraction. The following gases have been liquefied by the pressure stated after each, as determined by Dr. Faraday.

Sulphurous acid	2	atmospheres,	at	45° F.
Sulphuretted hydrogen	17	„	„	50°
Carbonic acid	36	„	„	32°
Chlorine	4	„	„	60°
Nitrous oxide	50	„	„	45°
Cyanogen	3·6	„	„	45°
Ammonia	6·5	„	„	50°
Muriatic acid	40	„	„	50°

CHAPTER VI.

LATENT HEAT.

138. When water is made to boil in an open vessel, if a thermometer be placed in the liquid, it will be found, as would be expected, that the temperature of the water will gradually rise until it reaches the boiling point (212°). After this, however great be the heat applied to the water, however long the water be kept boiling, no further rise in temperature will take place: the thermometer will remain at 212° as long as the water continues to boil. Also, it will be found that, after the water has begun to boil, and as long as it is boiling, the steam arising from it will be at the temperature of 212°.

139. Here is a striking circumstance. The water must continue to receive heat after it has begun to boil, as well as *before*, but nevertheless the temperature of the water and the steam remains stationary. What has become of the heat which entered the water after it began to boil? It has entered into the steam in a CONCEALED or LATENT state, and has been removed by the steam flying away as fast as it is formed. That this is the case, may be inferred from so much heat having disappeared, and may be proved *by recovering it from the steam.*

140. Let a tube be adapted to a flask or other vessel in which water is made to boil, and convey the steam arising from the boiling water into cold water. Let a known weight of *water, in the form of steam,* pass

into the cold water, which must also be of an ascertained quantity and temperature. Note the temperature to which the water has been raised by transmitting the steam into it. Now, add to a like quantity of water, at the same temperature, a quantity of *boiling water* equal in weight to that which had been passed in the form of steam into the first portion of cold water, and observe the temperature of the mixture. It will be found that the water to which the steam was added will be at a far higher temperature than that to which the boiling water was added—that is, the steam has given out more heat than the boiling water. But the steam and boiling water were equal in weight and temperature—therefore the steam must have contained a quantity of latent heat. We now see what has become of the heat which entered the water after it began to boil. It entered the steam; and, being in some peculiar relation to the water, becomes *hid*, or not discoverable by the thermometer, the usual test of the presence of heat. When the steam returns to the state of water, it restores this heat which it had absorbed into the concealed state; and, giving out the heat which it had as boiling water, and the additional heat which it had absorbed on becoming steam, must produce a much greater heating effect than the same weight of water at the same temperature.

141. Heat which thus eludes the thermometer is called LATENT HEAT. Heat which is discoverable by the thermometer, is termed FREE or SENSIBLE HEAT, or HEAT OF TEMPERATURE.

142. The quantity (or rather proportion) of heat, which becomes latent when water passes into the state of vapour, has been ascertained with considerable precision. This may be done in two ways:—

143. *First*, By estimating how long water requires to be heated (*i. e.*, how much heat must be added) after it has been brought to the boiling point, to dissipate it entirely in vapour, and comparing this with the time required to raise it to 212° from any givén point. To convert a given quantity of water at 212° into vapour, heat must be applied about $5\frac{5}{9}$ times as long as to raise the same quantity of water from 32° to 212° (*i. e.*, $5\frac{5}{9}$ times the quantity of heat must be added to the water). From 32° to 212° is 180°; 180° multiplied by $5\frac{5}{9}$ gives 1000° as the heat of conversion of water into steam.*

144. *Secondly*, The same may be estimated by transmitting a known quantity of steam into a quantity of water of a known weight and temperature, and observing how much the temperature of the latter is raised. In this way it is found that the heat absorbed by a given quantity of water at 212° in becoming steam, will raise $5\frac{5}{9}$ times the quantity of water at 32° to 212°. 180°, multiplied by $5\frac{5}{9}$, gives 1000° Fahrenheit, as the proportion of latent heat contained in steam.

145. The same takes place during the melting of solids and their congelation, or return to the solid condition. In melting, they absorb heat which does not raise their temperature; in congealing, they give out this heat into the free or sensible state. The latent heat of water is 140° Fahrenheit.

146. It thus appears that that heat which is engaged in effecting a change in the condition of a solid or liquid, is combined with it in such a way as not to affect its

* Any one may easily satisfy himself of this by experiment. Expose a quantity of water to a steady source of heat; note how soon the temperature of the water rises to 212°—how long before it is entirely vaporised.

temperature. These general laws of caloric may be expressed in a few words. When solids become liquid, and when liquids become gaseous, they absorb a quantity of caloric, which does not raise their temperature. They evolve this caloric into the free or sensible state, when they return to their former condition. These laws of heat were developed by the celebrated chemist, Dr. Joseph Black, about 1762.

147. Though of high interest and importance in other applications of heat, and in relation to precise calculations as to the quantity of heat required to produce a certain effect, they are not essential to an understanding of the mechanical operation of the steam-engine, nor was it by a knowledge of them that Watt effected his grand improvements, as has been erroneously supposed. "These improvements," says Watt, "proceeded upon the old-established fact, that steam was condensed by the contact of cold bodies, and the later-known one, that water boiled *in vacuo* at heats below 100°." It will be seen, as we go along, that Watt's improvements have no connection with the laws of latent heat, and would as readily have occurred to him though these laws had never been known.

148. When water boils at temperatures lower or higher than 212°, it appears that still the same quantity of heat is always required to vaporise the same quantity of water; the latent heat being as much greater as the sensible heat is less, when the water is made to boil at low pressures; and as much less as the sensible heat is greater, when water is boiled at high pressures: the sum of the free and latent heat of steam at all pressures being 1180°—that is, at 212°—1000° of latent, and 180° (reckoning from the freezing point) of sensible

caloric. Hence there would not be any economy of heat in raising steam at low temperatures, as was at one time supposed.

149. It appears, also, that equal weights of different bodies require different quantities of heat to raise them to the same temperature, a fact generally expressed by saying that the *specific heats of bodies are different.* A body which requires much heat to raise its temperature, is said to have *a high specific heat,* or a great *capacity for heat,* and *vice versâ.* Now, the specific heat of an aërial body is greater as its volume increases, continuing the same in quantity or weight; increasing with the bulk, decreasing as the density and elasticity increase. Hence, when aërial bodies are rarefied, they absorb heat into the latent state, to satisfy their increased specific heat. When condensed—having now a less specific heat—they give out heat into the sensible condition. Thus, rarefaction of a gaseous body causes cold; compression causes heat. Hence the cold in the upper regions of the atmosphere, where the air is rare, and therefore requires more heat to raise or keep up its temperature than the dense, lower strata of air. Hence a thermometer sinks in temperature when placed in the receiver of an air-pump, from which the air is quickly withdrawn. Hence the syringe for procuring a light, which is simply a cylinder in which a piston works; the latter being suddenly forced down, compresses the air, and the heat thus evolved kindles some tinder in the cylinder.

150. Several of the phenomena of heat are well illustrated by a beautiful instrument, devised by Dr. Wollaston, called the Cyrophorus, or Frost-bearer. It consists of a glass tube bent and expanded into a bulb at each extremity, and containing only pure water and watery vapour.

Before it is closed, the water is divided between the two bulbs, and made to boil in each; the vapour escaping by the aperture in the middle of the tube, so that the vessel cannot contain any air. While the liquid is boiling briskly, the aperture (*a*) is suddenly closed by directing the flame of a blowpipe across it.

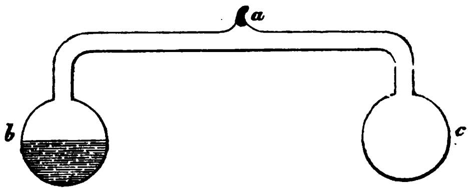

FIG. 7.

151. With this instrument the following striking experiment may be performed :—Collect all the water in one bulb, and place the empty bulb in a freezing mixture. In a short time the water will be frozen, illustrating three points in the phenomena of heat :—*First,* That water evaporates rapidly as the pressure on its surface is diminished ; *second,* That it evaporates at very low temperatures ; and *third,* That, during evaporation, an immense quantity of heat is absorbed into the latent state, the adjoining liquid being robbed of sensible heat to supply this demand.

152. The vapour in one bulb being condensed by the freezing mixture, the vapour in the tube and upper part of the other bulb expands and rushes into the bulb in the freezing mixture. The pressure upon the surface of the liquid being thus reduced, and the space above it containing less vapour than its temperature can support, evaporation takes place from the surface. But any vapour which rushes into the other bulb is immediately

condensed: hence, evaporation from the surface goes on with great rapidity, and the temperature of the liquid is so much reduced by the vapour absorbing heat into the latent state, that it actually freezes. If the bulb in the freezing mixture be examined, it will be found to contain some water or ice, though there was nothing but vapour in it at first. A good freezing mixture is obtained by mixing salt with snow or pounded ice; but the experiment may be done even in mild weather, when no snow or ice can be procured, by means of other freezing mixtures, the preparation of which is described in treatises on Chemistry or on Heat.

PART II.

CHEMICAL RELATIONS OF WATER, AIR, FUEL, AND IRON.

CHAPTER I.

WATER.

153. **Water**, in its purest state, consists solely of two elementary bodies; **Oxygen** and **Hydrogen**. These two substances are found in the aërial state when uncombined with other bodies, or each other; they are then clear, colourless, and transparent; and are incapable of being reduced to the liquid or solid form by cold or pressure, or both combined. The following tables will illustrate the composition of water.

COMPOSITION OF WATER.

Name of Gas.	Weight.		Bulk.
Oxygen	8	Con-	0·5
Hydrogen . . .	1	densed	1·0
Steam at 212° . . .	9	into	1·0

Proportions necessary for forming water in 100 parts of the gases.

	By weight.		By measure.	
Oxygen . . .	88·9, or	8	33·34, or	1
Hydrogen . . .	11·1, or	1	66·66, or	2
Mixed . . .	100·0	9	100·00	3
Combined . . .	100·0	9	66·66	2

154. When the gases combine, a condensation ensues. They are reduced one-third in bulk. The steam formed occupies only the bulk of the hydrogen. Hence, when steam is decomposed (its elements separate), there must be an increase in bulk of *one-half*. Also, the gases into which it is formed *are not condensible* by cold, as steam is. Thus, while steam is easily condensed, and made the means of procuring a vacuum, its uncombined elements are totally unfit for such a purpose.

155. Some of the metals, as iron and zinc, possess the property of decomposing water when they meet at a high temperature. The metal abstracts the oxygen, with which it unites and forms a solid crust of metallic oxide at its surface. The hydrogen thus eliminated assumes that form which is proper to it when uncombined, and becomes a clear, colourless, incondensible gas, equal in bulk to the steam from which it was formed. The hydrogen is inflammable; and, if it meet with the necessary quantity of free oxygen (as in air) and a sufficiently high temperature, it will burn, uniting with the oxygen, and forming vapour of water. When hydrogen and oxygen unite, great heat is evolved, and the gases are thereby enormously expanded for a moment; some have said so much as to occupy fifteen times their former bulk. At all events, they expand with great force, capable of bursting very strong vessels if they are confined, and causing a loud report when the experiment is performed with the proper proportion of the gases in a stout glass jar.

156. But water such as we have been just speaking of is nowhere met with in nature. It is pure distilled water, found only in the laboratory of the chemist. Common water contains in solution small quantities of air,

and of any soluble earthy matters it may have been in contact with, as sulphate of lime, &c. The water of the Clyde contains in an imperial pint (34½ cubic inches, or in weight 8750 grains,) 1·14 grains of earthy matters, and about 1-35th of its bulk of gases. The earthy matters consist chiefly of muriate of magnesia, sulphate of soda, common salt, silica, or flinty earth. Of the gaseous matters, 1-20th is carbonic acid, and the remaining 19-20ths are common air. The proportions of these ingredients vary in different streams; but all contain some earthy matters and gases in solution; besides what may be present, mechanically suspended in the liquid.

157. Sea-water contains a much larger proportion of earthy matters. The following table shows the chemical composition of 1000 parts by weight of the water of the English channel, analysed by Dr. Schweitzer:—

Water	964·74372
Chloride of Sodium	27·05948
——— Potassium	0·76552
——— Magnesium	3·66658
Bromide of Magnesium	0·02929
Sulphate of Magnesia	2·29578
——— Lime	1·40662
Carbonate of Lime	0·03301
	1000·00000

This gives, as nearly as possible, 1-27th of saline and earthy matter, and 26-27ths of pure matter of water; or about thirty-five parts in the thousand are saline and earthy matter. The water of the Frith of Forth, examined by Dr. Murray, contained, in 1000 parts—

Pure matter of Water	969·691
Common Salt	22·001
Sulphate of Soda	3·316
Muriate of Lime	0·784
Muriate of Magnesia	4·208
	1000·000

This analysis gives about thirty parts in the thousand as saline and earthy matter; or nearly 1-33rd—the proportion of saline matters being less, as might be expected, near the shore and mouths of rivers, than out in the ocean.

158. When water containing any gases and earthy matters is boiled, the gases rise in the gaseous form with the first portions of vapour that are expelled; so that the steam of common water always contains a small portion of air. When the steam condenses into water, this air does not entirely condense along with it: a great part retains the gaseous form, as water cannot absorb much air when warm, and the water formed by the condensed steam is very warm at first. Hence one use of the air pump in Watt's engine.—The earthy matters remain in the vessel in which the water is boiled; and, when there is not sufficient water left in the vessel to retain them in solution, fall down in the solid form. If the same vessel be used for boiling successive portions of water, and be not frequently cleaned out, a crust of these earthy matters will form at the bottom, which will gradually thicken, and may lead to injurious consequences, as the earthy crust is a slow conductor of heat—that is, takes heat slowly from bodies, and gives off heat slowly—in short, gives heat a very slow passage through it. This will be explained more particularly in the chapter on iron.

A considerable portion of the deposit in steam-boilers consists of the insoluble carbonate of lime—previously maintained in solution by the free carbonic acid present in the water, which being driven off by the heat, the carbonate is precipitated.

CHAPTER II.

AIR.

159. The air is composed of four ingredients, oxygen, nitrogen, carbonic acid, and watery vapour. Oxygen forms about one-fifth, nitrogen four-fifths—both by weight and measure, as these gases do not differ much in specific gravity. The watery vapour is about $\frac{1}{100}$; and the carbonic acid varies from $\frac{1}{1000}$ to $\frac{1}{2000}$. Oxygen is the active ingredient, being the leading agent in respiration, and in combustion or burning, which consists in a rapid combination of the oxygen with the combustible body. Carbon (charcoal) and hydrogen are the combustible elements usually met with. Every 6 parts of carbon (by weight) unite with 16 parts of oxygen, and form 22 of carbonic acid: while 1 part of hydrogen requires 8 of oxygen for its combustion, and forms 9 of watery vapour. Carbonic acid and watery vapour are thus, in all ordinary cases, the products of combustion, which is effective in proportion to the amount of oxygen consumed. Oxygen has also a disposition to unite with metals, and convert them from a firm tough body to a brittle substance, called *oxide* of the metal so altered—commonly called *rust*. The nitrogen is of an inert passive nature, its chief operation being to dilute the oxygen, and render it less energetic in its action. The watery vapour and the carbonic acid tend to damp or check combustion, but promote the oxidation or rusting of metals.

CHAPTER III.

FUEL.

160. The kinds of fuel used for the production of heat to vaporise water for steam-engines, are WOOD, TURF, CHARCOAL, COKE, COAL, ANTHRACITE, TAR, or REFUSE WOODY MATTER, such as *saw-dust, tanner's spent bark,* &c. Of all these the chief combustible ingredient is carbon. It forms the principal part of wood, charcoal, coke, and anthracite—the latter (called also blind-coal, glance-coal, Welsh-coal, stone-coal) contains a considerable proportion of earthy matters, silica, &c., which remain as ashes after combustion. It is the mineral chiefly used as fuel in the United States of North America. Coal contains, besides carbon, hydrogen, which is also a combustible ingredient, and some oxygen and nitrogen. Tar and wood also contain hydrogen. Where the fuel contains hydrogen, it burns with a yellow flame. Where there is no hydrogen, the fuel burns without flame, or only a little of a bluish colour, usually with a steady red light like cinder, and a more uniform heat is sustained. Such a fuel is found in charcoal and coke. The former is prepared by heating wood in close vessels; the latter from coal, by a similar process. Anthracite contains no hydrogen. A new composition called "prepared fuel" has lately been introduced. It is composed of screened coal (coal otherwise too small for use), river mud, and tar, formed into blocks of the same size and shape as a common brick; and it was expected to have

the advantage, so important in steam navigation, of concentrating a great quantity of combustible matter in a small compass.

161. The following tables of the composition of the different kinds of coal, and quantity of coke and ashes they yield, are from analyses by Dr. Thomson :—

	Caking Coal.	Splint Coal.	Cherry Coal.	Cannel Coal.
Carbon	75·28	75·00	74·45	64·72
Hydrogen	4·18	6·25	12·40	21·56
Nitrogen	15·96	6·25	10·22	13·72
Oxygen	4·58	12·50	2·93	0·00
	100·	100·	100·	100·

		Volatile Products.	Weight of Coke.	Incombustible Ash.
1000 parts of Caking Coal	give	226	774	15
Splint Coal		352	647	95
Cherry Coal		477	422	100
Cannel Coal		600	400	110

These kinds of coal differ considerably in composition in different places, which accounts for the discrepancies in the analyses given by various chemists. There is also a little sulphur frequently present in coal.

162. In the combustion of fuel, a chemical action goes on, in which the carbon and hydrogen unite with oxygen, furnished by the air ; so that a free and ample supply of air is essential. It has been estimated that a pound of coke or Welsh-coal (containing no hydrogen) requires about two pounds of oxygen for combustion. This is about twenty-four cubic feet of oxygen. This quantity of oxygen will be contained in 120 cubic feet of air.

About a third of the air which enters ordinary furnaces, passes through without aiding in the combustion; so that, to furnish the necessary quantity of oxygen, about 180 cubic feet of air are required for the complete combustion of every pound of coke. It is considered that the combustion of one pound of good coal or coke should evaporate from $5\frac{1}{2}$ to $9\frac{1}{2}$ lbs. of water, according to the variety, or that about 8 lbs. of coal should evaporate 1 cubic foot of water.

163. Smoke is the result of the incomplete combustion of fuel containing hydrogen, and consists of carbon in fine powder (forming soot when deposited), carbonic acid, carbonic oxide (a compound of carbon with half the quantity of oxygen), watery vapour, compounds of carbon and hydrogen (called carburetted hydrogen), compounds of nitrogen and hydrogen (containing ammonia), &c. Hence, as the combustibles carbon and hydrogen are leading ingredients in smoke—there is loss of fuel where there is smoke—in short, there is such loss whenever all the carbon is not converted into carbonic acid, and all the hydrogen into watery vapour. Even where there is no hydrogen there may be loss, from part of the carbon being converted into carbonic oxide: the same amount of carbon having been capable, under proper management, of combining with twice the quantity of oxygen, when a much greater amount of heat would be given out.

164. Combustion is imperfect, chiefly from three causes—an insufficient supply of oxygen—the presence of too much carbonic acid—and too low a temperature.

165. If there be not an abundant supply of air, part of the carbon is precipitated in fine powder, and carried off in suspension—part forms carbonic oxide instead of carbonic acid—part unites with hydrogen, and escapes as

carburetted hydrogen. Hence the necessity for arrangements which shall ensure not only an ample supply of air to the mass of fuel, but air to penetrate the burning mass, so that the supply shall be abundant at each part. —Next, it is well ascertained that combustion in air containing abundance of oxygen is checked by the presence of a moderate quantity of carbonic acid, the very gas produced by combustion. A candle does not burn in air if it contain *one fifth* of its bulk of carbonic acid. Hence it often happens that a large quantity of the air which enters a furnace, being mixed with this gas from the previously burned fuel before it reaches the place where it should be of service, is thereby rendered unfit for combustion. It is not only of no use, it is detrimental, carrying off a considerable portion of heat.—Lastly, it is found that combustion does not commence nor continue unless the air be heated up to a high temperature; and if the air be cold, a large amount of heat is first consumed in heating it up to the necessary point; which heat, when it can only be had from the fuel, may in some cases check the combustion altogether. Hence, many combustibles, which are not in a state to burn in impure air at a low temperature, might burn freely if the air supplied were pure, and heated before it comes in contact with them. A temperature of about 1200° is believed to be required to support combustion.

166. It is by the application of these principles that smoke may be prevented, and the greatest amount of heating power procured from the combustion of fuel. This is usually done by introducing the fresh fuel so that its smoke passes through previously ignited fuel, and is burned,—by admitting air to meet the smoke just on leaving the half-burned mass when it is at a high tempera-

ture, and readily burns on meeting with fresh air; by contrivances for admitting air at various points; and by heating the air previously to its entering the furnace.

CHAPTER IV.

IRON.

167. Iron is the material used for all large steam-boilers, interposed between the heat and the water to be boiled. Malleable iron is generally employed. It will bear a considerable heat without injury; but, if too strongly heated, it will *oxidate* (commonly called rusting, or corroding),—a crust of brittle *oxide of iron* forming upon its surface, whether exposed to air or to water. The tenacity or strength of iron varies with its temperature. It is greatest at 550°—$\frac{1}{7}$ less between 32° and 80°, and at 720°; $\frac{1}{2}$ less at 1050°; $\frac{2}{3}$ less at 1240° (red heat), $\frac{6}{7}$ less at 1317; melts at about 3000°. It is not improbable that malleable iron, much in contact with the carbonaceous matter of fuel, and at a high temperature, may combine with some carbon, and thereby become impaired in its tenacity, acquiring the properties of cast iron. Iron is a good conductor of heat, and, when employed as a boiler, is in no danger of rusting, (or burning, as it is sometimes termed,) if there be plenty of water in contact with it, to carry off the heat in the form of vapour, and if the vapour have free exit. If the vapour be confined, however, from any cause, its temperature will rise, and the heat, not being carried off, will tend to accumulate both in the vapour and the boiler, and thence to corrode or burn the boiler. If the water be entirely

dissipated, then also the heat, not being carried away in the latent state by vapour, will accumulate and burn the boiler—that is, enable it to combine with the oxygen of the air, which it does not do at a moderate temperature. Or, if there be an earthy crust lining the boiler, this (a slow conductor) will transmit the heat so slowly through it, and give it off so slowly to the water, that the boiler will be apt to be destroyed from the action of the fire. Where, from any of these causes, the boiler is at a very high temperature, it has been conjectured (though never proved to have taken place) that the iron may decompose the steam in the interior, and replace it by the incondensible gas hydrogen, retaining the oxygen, in the crust of oxide formed.

168. This has been considered a cause of the explosion of steam-boilers. The difficulty here is to account for the supply of oxygen to form an explosive mixture with the hydrogen. Hydrogen is not separated from steam by a hot metal, unless the oxygen of the steam be abstracted by the metal, in which case the oxygen is fixed down in the form of a solid crust of oxide. If explosions ever take place from this cause, the necessary quantity of oxygen must be derived from a leak in the boiler admitting atmospheric air, which can hardly be supposed to be the source of the oxygen for an explosion; so that we may regard it as being extremely improbable that the decomposition of the steam can ever lead to the formation of an explosive mixture in a steam-boiler. Besides the above considerations, it is to be borne in mind, that, even supposing the necessary quantity of oxygen to be present, there might be no explosion, from two causes:—1. The want of a sufficiently high temperature; 2. The presence of the steam in large quantity in

the gaseous mixture.—The American Committee, which inquired into the causes of the explosions of steam-boilers, gave it as their opinion, from experiments instituted, that this is not a cause of such explosions.

169. Danger may also arise from a deficiency of water, when the sides of the boiler may become red hot. If water then come suddenly in contact with them, a large quantity of vapour may be suddenly formed, causing an explosion. This, there is reason to believe, is a frequent cause of the explosion of steam-boilers.

170. Sulphur has also a tendency to unite with iron when they meet at a high temperature ; hence fuel containing this element should be avoided, otherwise the boiler may be corroded and weakened.

PART III.

HISTORY AND DESCRIPTION OF THE STEAM-ENGINE.

It is not uninteresting to trace the progress of a great invention, from the first rude attempts till it attains a somewhat perfect form—to observe how often men have been on the brink of the discovery, and yet allowed it to escape them, and to mark the successive changes it undergoes; and there is, perhaps, no better or easier way to understand the later and more complex forms it assumes, than tracing it from the first simple conception, and at each stage contrasting it with its previous condition. We shall, therefore, prefix to the description of the modern engine a brief sketch of the progress of the invention from the earliest records.

It will smooth the way very much in the investigation of the subject, to examine shortly the various modes of applying steam as a power, and divide the invention into separate stages as much as possible. This will enable us more easily to come to a judgment on the comparative value of each step.

171. There are two modes of using steam for the production of force or power. 1. *Directly*, when the force or pressure of the steam itself produces the power. 2. *Indirectly*, when the steam is used to form a vacuum,

and thereby to give effect to some power acting into the space where the vacuum is made.

I.—DIRECT ACTION OF STEAM.

172. The direct force of steam has been proposed to be applied to the production of motion in *three* principal modes.—*First*, in point of simplicity, though not in order of chronological development, by the impetus which it has on issuing from a vessel in which water is boiled. Every one has noticed that the steam from a boiler is projected with a considerable degree of force. On the principle of the windmill, this current of steam in motion will communicate motion to the vanes of a wheel properly adjusted to receive it, and thus turn the wheel. This very simple plan for steam power was proposed by Branca in 1629, and by Kircher some years after.

173. *Second*. The pressure of confined steam. This is the next mode, in respect to obviousness and simplicity. If water be boiled, and the steam be prevented escaping, it will accumulate, and press with great force on the bodies which confine it, pushing aside, with more or less power, those which present least resistance—and thus raising liquids in contact with it, bursting the vessel in which it is confined, or moving a piston along a cylinder—according to the mode in which it is applied.

The power of confined steam has been made use of in two principal modes: 1. To raise water, to which it is directly applied, as in the plans of Porta, De Caus, Savery, and Papin's second scheme.—2. to press a piston through a cylinder, and thus cause a rectilineal motion, which may be adapted by appropriate machinery to any purpose; as done by Leopold and Watt.

174. *Third.* Steam may be employed as a source of power, on the principle of the re-action of a fluid issuing forcibly from a tube, and if projected sideways, thereby tending to push back the tube in a direction opposite to that in which the fluid issues, as in Barker's mill. If the tube be made to turn on a pivot, and a continued stream issue sideways from its extremity, the tube will be turned continuously round, and thus a rotatory motion will be procured. This is the principle of the first steam machine, Hero's Æolipile, described 130 years B.C., and it was revived by Kempel in 1794, and brought lately into operation by Avery in America, and by Ruthven in this country.

II.—INDIRECT ACTION OF STEAM.

175. Steam is condensible into water; its elastic force is thereby reduced almost to an insensible amount, a nearly perfect *vacuum* being produced. If steam be driven into a vessel containing air, and with an aperture to permit the air, or air and steam, to pass out, the air will soon be expelled, and the space filled solely with steam. This aperture being now shut, and also that by which the steam entered, and the steam being cooled, it condenses, and the external air, or any other force acting towards the vacant space, not being now resisted, yields a source of force or power which may be easily applied so as to produce motion.

Such are the modes in which steam may be used in the production of motion.

176. To produce the steam-engines of Savery, Newcomen, and Watt, the three which have come into use, some one or more of the preceding general properties of steam are called into action. But besides these, there

are a number of points in the mechanical adaptation of the parts, which are essential to the construction of these engines. The following statement embraces the leading conditions of every kind, connected both with the steam and with the mechanism necessary to the invention of these engines, and which therefore have a value in relation to the steam-engine, and entitle the discoverer to a place among those who contributed to the development of steam power. Upon *analysing* the steam-engine, we find the following leading and distinct ideas entering into its construction and operation :—

Properties of Steam.

1. That a steady and continuously-acting power is procured by the confinement and regulated escape of the steam of boiling water.

2. That when steam is condensed, a vacuum is produced, into which the adjoining bodies will tend to rush.

3. That steam is most rapidly condensed by projecting water into it.

4. That the vapour of water has a considerable force or pressure, even at temperatures much below the boiling point, as 100° to 140°.

5. That a vacuum may be produced by steam, without cooling the vessel in which it is contained, if a communication be made between it and another vessel in which a continual vacuum is kept up.

6. That if the external pressure (the compressing force) on a quantity of confined steam be less than the force of the steam, it will tend to expand, and cause motion in the bodies confining it.

7. That the steam of common water contains air which does not condense on being cooled.

Mechanical Contrivances.

1. That a piston may be pushed along a cylinder by the force of an aerial body beneath it, as steam, or the gases formed by the ignition of gunpowder.

2. That if a vacuum be produced in a cylinder below a piston, the atmospheric pressure will cause the piston to descend.

3. That an alternate rectilineal motion is easily transmitted to a distance by a lever (beam) working on a pivot.*

177. These modes of applying steam, these principles of its action, and these mechanical contrivances being kept in view, we find the following successive stages, and distinct ideas, in the development of the use of steam as a moving power ;—at the side are shown the names of the individuals who contributed each step. It is only by such an analysis that we can judge of the comparative value of the services of the successive labourers in this great work.

1. The publication of the fact that steam may be made to yield a force or power.	HERO, 130 B. C. GARAY, 1543. MATHESIUS, 1571. RIVAULT, 1605.
2. The publication of the fact that steam may be made to yield a *steady continuously-acting* power.†	HERO, 130. B. C. GARAY, 1543. BRANCA, 1629. WORCESTER, 1663.

* I have here given only those leading mechanical contrivances used in NEWCOMEN'S Engine. Those in WATT'S Engine are so numerous, that they would require considerable space, and would render the subject complex: they will be alluded to separately afterwards.

† It will be at once perceived that this, a steady continuously-acting

3. The publication of the fact that water may be raised by the force of steam, coming from boiling water, and confined: and construction and description of an apparatus by which this would be effected *on the small scale.*	PORTA, 1606.
4. The publication of the fact that if a space to which water has free access be filled with steam, and the steam be then condensed, the water will rush into that space.	PORTA, 1606.
5. The proposal to apply the power of steam as in No. 3. (though in a much less perfect mode) to use for raising water *on the large scale.**	DE CAUS, 1615.
6. The suggestions to procure a power or force by the pressure of the air on a piston in a cylinder, a vacuum being made below the piston; and to raise the piston by gunpowder.	GUERICKE, 1672. HAUTEFEUILLE, 1678.
7. The directing public attention forcibly to the application of steam for raising water, and actually raising large masses of water great heights by steam power, with obscure hints as to the plan.†	WORCESTER, 1663. MORLAND, 1683.

property, is an essential element in the application of steam as a moving force. It includes No. 1—but is something additional. No. 1 does not include it—may exist without it; as in RIVAULT'S Experiment, &c.

* The apparatus of DE CAUS, containing nothing beyond PORTA'S—indeed, inferior to it in a most important point,—is not mentioned. The idea of use on the large scale is all that is DE CAUS'S.

† Few, I suppose, will dispute, that it lends some aid to the progress

8. Suggesting to procure a vacuum below a piston by boiling water under it, and then condensing the steam, instead of by the air-pump; the air's pressure then pushing down the piston.* — PAPIN, 1690.

9. Planning, constructing, and bringing into operation an Engine, to *raise water* great heights, partly by the ascent of the liquid into a vacuum formed by condensing steam, and partly by the force of the steam directly applied; and requiring a great number of different parts and different principles, ingeniously adjusted—in short, *the first steam-engine that ever did any work.* — SAVERY, 1698.

10. The planning, constructing, and bringing into operation an efficient engine, requiring a great number of different parts, ingeniously adjusted *to work a common pump*—by means of a CYLINDER, with a PISTON moved by atmospheric pressure, a vacuum being procured below the piston by condensing steam, and the motion being transmitted by a BEAM. — NEWCOMEN and CAWLEY, 1705.

of an invention, to have it proclaimed as possible and done, even though the manner of doing it be not explained precisely.

* Besides this, there is some reason to believe that PAPIN also raised the piston by the force of the steam coming from the water boiling under it.

11. The planning, constructing, and bringing into operation a steam-engine for *raising water*, embracing several important new inventions, and far more efficient and economical than Newcomen's.	James Watt, 1769.
12. The planning, constructing, and bringing into operation a steam-engine, with several new inventions, and some new applications, and adapted for the great end of *impelling machinery*.	James Watt, 1784.

178. When steam about or near the ordinary pressure of the atmosphere is used, the engine is called a *low pressure*, or *condensing* engine. It can have no motive power if resisted by the air's pressure. To give such steam an impelling force, the space towards which it acts must be a vacuum, or nearly so. The vacuum being procured by the condensation of steam—hence the name "condensing engine." Where there is not a vacuum made, the steam having to balance the air's pressure, besides exerting a motive power, must be of a very high pressure. Such engines are called *high pressure*, or *non-condensing*.

SECTION I.

ÆOLIPILE OF HERO.—ORGAN OF GERBERT.—GARAY'S STEAM BOAT.—FOUNTAIN OF PORTA AND KIRCHER.—RIVAULT'S BOMB.—ENGINES OF DE CAUS, BRANCA, WORCESTER, AND MORLAND.—PAPIN'S FIRST ENGINE.—130 B.C. TO 1690 A.D.

179. In many ancient records we find faint glimmerings of a knowledge of the power of steam. Earthquakes and volcanic eruptions were attributed to the sudden vaporization of water; and it is related of an architect of the time of Justinian, that by means of steam-pipes issuing from a boiler, and opening in the partition between his own house and that of a neighbour who had given him some offence, he produced artificial earthquakes in his neighbour's mansion, and succeeded in creating great alarm, and rendering him very uncomfortable. The sounds emitted at sunrise from the famous statue of Memnon, in Egypt, have been attributed to the movement of the vapour raised by the action of the sun's rays from water concealed within: and the sudden escape of pent-up steam was said to have been employed by the Teutonic priests as a means of awing their followers, by loud explosions accompanied by clouds of vapour made to issue from the heads of their images.

ÆOLIPILE.—B.C. 130.

180. The first instance on record of the force of steam being applied to produce continuous motion, is that of the Æolipile, a philosophical toy, described in the writings of Hero of Alexandria, who flourished

during the reign of Ptolemy Philadelphus, about 130 years before the birth of Christ. This writer was distinguished for his mechanical knowledge. Besides the Æolipile, described in the next paragraph, he also was acquainted with the forcing-pump for raising water (the invention of Ctesibius); the beautiful contrivance for an artificial fountain, still called Hero's fountain; a machine for producing a rotatory motion by a jet of heated air; and many other curious mechanical inventions.* The following cut will explain the action of the Æolipile.

181. The boiler, *a*, is covered with a lid, into one side of which the pipe *b* is inserted, which, after rising vertically, is bent at right angles, and transmits the steam into the globe *g*, the globe revolving round the arm *d*. From the other side of the boiler rises a support, *c*, which is bent at right angles, and terminates in a pivot, on which the globe revolves. The globe has two small tubes issuing from it, opposite to each other, and at right angles to the line of the bent parts, *d e*. These tubes are bent close to their open ends, *m n*, at right angles, and in *opposite directions;*

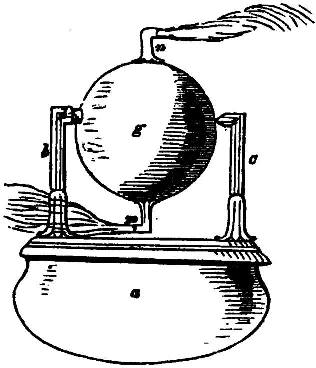

Fig. 8.

* Many of which, there is reason to believe, were used by the ancient priests to awe the people by exhibiting apparently miraculous power, as causing blood (in reality wine) to flow from figures or statues, &c.

or, they may be straight and closed at the ends, if there are two apertures very near the ends, but *on opposite sides*. Indeed, *one tube* would do ;—if there are two, they must be so placed that the steam issues from them in opposite directions. When the water in the vessel *a* is made to boil, the steam passes through the pipe *b* into the globe, and thence out through the ends or apertures in the tubes *m n*, and, acting on the side of the tube opposite to the aperture, will cause it and the globe along with it to move in a direction opposite to that in which the steam issues ; and, the supply of steam being kept up, a continuous rotatory motion of the machine will be induced.

182. The same may be effected in a simpler way, by forming the steam in the vessel *a* itself, the globe being removed from the boiler and tubes *b c*, and made to revolve on supports, by rods projecting from its surface in the line of the notches. This was proposed, in a book published at Leipsic in 1597, as a means of turning a spit for roasting meat.

183. The principle of the Æolipile—the same as that which produces the motion in the water-power engine called Barker's Mill—has not till lately been made use of in any modern engine ; but it unquestionably exhibits motion produced by the force of steam, and which might be transferred to machinery for some useful purpose. It has the merit of great simplicity, and was introduced some years since as a moving power by an American engineer. See "Avery's Engine," in the chapter on Rotatory Engines.

184. Ruthven, of Edinburgh, proposed a steam-boat engine on this plan, in which the power of the engine is applied to pump water into the vessel, and then expel it

by an open pipe at each side. The pipes are so constructed that they can be turned in any direction. When both are pointed backwards, the vessel is propelled forwards; backwards, when both are directed forwards. By pointing one towards the stern, the other towards the bow, the vessel is turned to either side, as may be desired; and when both are pointed down, the vessel stops. It was once proposed by some one to have a steam-boat which should be propelled simply by a steam-boiler, with a pipe pointed back from the stern of the vessel, from which the steam should issue. The force in all these cases is of the same nature as that which causes the recoil of a musket, or the ascent of a rocket.

185. Hero also describes a machine for raising water (it would do so, certainly, but in drops only) by the action of the sun's rays on the air in a globe two-thirds full of water, the air expanding and pressing the water through a tube.* And this description seems to have suggested to Baptista Porta the contrivance described in paragraph 190 (which is, in fact, a steam-engine), and to De Caus some of his ingenious machines for indicating the heat of the weather, raising water by the sun's heat, &c. Hero's "Pneumatica," the fruit of the union of Greek genius and Egyptian art, was a perfect storehouse of

* Hero's work is now very scarce. It is stated by a writer in the Mechanics' Magazine, vol. xli. p. 10, that in this celebrated work "we are shown how liquids may be forced by the pressure of steam above their level—how solid weights may be raised and lowered by steam—how bodies may be made to revolve by steam—and even how the pressure of steam may be augmented and regulated. The mechanical instruments, moreover, by which these purposes are effected, are precisely the same as those which figure most prominently in our modern steam-engine machinery, as cylinders and pistons, oscillating beams, parallel motions, weighted levers, spindle valves, &c." Surely an English translation of this repository of ancient art is a desideratum in our literature.

experimental science, and to it we owe in a great measure the experimental turn of inquiry which has led to the great results of modern science and art.

ORGAN OF GERBERT.—12TH CENTURY.

186. In his "Historical and Descriptive Anecdotes of Steam-Engines," and of their inventors and improvers—a very interesting work—Mr. Robert Stuart has pointed out a passage in Malmsbury's "History," from which it would appear, that, about the twelfth century (1125), there was at Rheims an organ, in which steam (*heated water* is the term) was in some way instrumental in producing the sounds. The passage is as follows:—"In the church of Rheims are still extant, as proofs of the knowledge of Gerbert—a public professor of the schools—a clock constructed on mechanical principles, and a hydraulic organ, in which the air, escaping in a surprising manner by the force of heated water, fills the cavity of the interior of the instrument, and the brazen pipes emit modulated tones through the multifarious apertures." It does not appear whether steam was actually used, or the heated water only employed to expand the air, as the words would almost indicate; if the former, this is certainly the first useful application of steam.

STEAM-BOAT OF GARAY.—1543.

187. At Barcelona, in the year 1543, a Spanish sea-officer, called Blasco de Garay, propelled a vessel on the water without sails or oars, "by an apparatus, of which a large kettle, filled with boiling water, was a conspicuous part." From the traditions on the subject, it appears that the experiment—which was done by order of the

famous Emperor, Charles V.—was considered as successful, and that Garay was promoted and rewarded. But it went no further—perhaps, as Dr. Renwick remarks, because he was "too far in advance of the spirit of his age to be able to introduce his invention into practice;" and it died with him, as he kept his plan strictly secret. If this account be authentic, Garay must have possessed, considering the times, an extraordinary degree of knowledge of the properties of steam and of mechanical skill.*

* The subjoined appeared in the newspapers lately:—A letter from Madrid, published in the *Commerce*, French paper, contains an account of the discovery in the Royal archives of Salamanca of authentic documents, proving what has heretofore rested on vague tradition. The following extract is from a register kept by the Minister of the Marine:—"In 1542, Don Blasco de Garay, captain in the navy, (Capitaine de Vaisseau,) submitted to the examination of the Emperor Charles V. a machine moved by the steam of boiling water, by which ships, however large, could proceed on a calm sea without oars or sails. The Emperor ordered that a trial should be made, which took place in the Roads of Barcelona on the 17th June, 1543, and succeeded perfectly. This experiment was tried with a vessel of 200 tons burthen, named Santissima Trinidad, commanded by Captain Don Pedro de Learga, who had arrived at Barcelona with a cargo of wheat. The Emperor Charles V., and his son, afterwards Philip II., Don Enrique de Toledo, the Governor Don Pedro de Cardona, the Grand Treasurer Ravago, the Vice-Chancellor Don Francisco Gralla, a great number of other distinguished persons of Castile and Catalonia, and numbers of naval officers, some on shore and some on board the vessel, were present at the attempt. The Emperor, the Princes, and the other distinguished personages were astonished at seeing the ease with which the machine moved the vessel; but the Grand Treasurer, Ravago, thought it right to advise that the invention should not be adopted in the vessels of the state, because, according to his opinion, the machine was too complicated, and would be too expensive, and there would be reason to fear an explosion of the boiler."—"The special commission ordered to report on the experiment confined themselves to stating that a vessel moved by steam had first completed three leagues in two hours, and then a league in an hour, and that it could be made to move twice as swiftly as a common rowing galley. The Emperor did not pay any more attention to the invention of Don Blasco de Garay, but he presented him with 700,000 maravedis, and promised to raise him successively to the

188. A German writer, called Mathesius, in a volume of sermons, published in 1571, describes an apparatus somewhat resembling a steam-engine, and speaks of the "mighty effects that could be produced by the volcanic force of a little imprisoned vapour." Between that time and the end of the next century, when Savery constructed his engine, there are many notices, by various authors, of the effect of heat upon water—"the power of imprisoned vapour"—and hints for the construction of engines founded thereon. We shall allude to Rivault, Porta, De Caus, Branca, Worcester, Morland, and Papin.

RIVAULT.—1605.

189. "In the year 1605," says M. Arago, "Florence Rivault, a gentleman of the bedchamber to Henry IV., and the preceptor of Louis XIII., discovered that an iron ball or bomb, with very thick walls, and filled with water, exploded sooner or later when thrown into the fire, if *its mouth were closed*, or, in other words, if you prevented the free escape of the steam as it was generated." M. Arago assigns to this rude experiment a considerable degree of importance in the progress of the invention of the steam-engine:* and even speaks of its capability of

highest rank in the Spanish navy. The late M. Raynouard, of the Académie Française, has left among his papers a ballad in honour of Garay, which was sung in the streets of Barcelona in 1543."

* The following, attributing to Leonardo da Vinci (who flourished in the 15th century), the knowledge of a superior form of the above experiment attributed to Rivault, appeared lately in the newspapers:—"M. Delecluze has lately made a discovery among the manuscripts of Leonardo da Vinci, carrying back a knowledge of the steam-engine to at least the 15th century. He has published, in the *Artiste*, a notice on the life of Leonardo da Vinci, to which he adds a fac-simile of a page from one of his manuscripts, and on which are five sketches with the pen, representing the details of the apparatus of a steam-gun, with

numerical appreciation. But there is no evidence whatever that Rivault had any idea of precise calculations as to the force procured.

BAPTISTA PORTA.—1606.

190. The celebrated Baptista Porta, an Italian philosopher, inventor of the camera obscura, was the author of several ingenious works, and, among others, a commentary on the "Pneumatica" of Hero, in which he describes and gives a drawing of a *steam-fountain*, which wanted nothing but the "idea of such an application," and a proportional magnitude, to form a steam-engine for raising water. It will be understood from the adjoining cut. A tube (*a b*) coming from a boiler or retort in which steam is formed, and open at

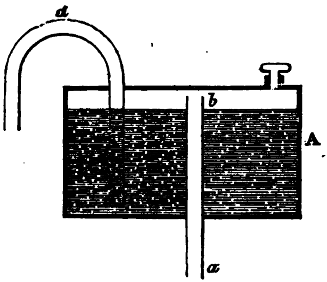

FIG. 9.

an explanatory note upon what he designates under the name of 'Architonnerre,' and of which note the following is a translation:—"Invention of Archimedes.—The Architonnerre is a machine of fine copper, which throws balls with a loud report and great force. It is used in the following manner:—One-third of this instrument contains a large quantity of charcoal fire. When the water is well heated, a screw at the top of the vessel, which contains the water, must be made quite tight. On closing the screw above, all the water will escape below, will descend into the heated portion of the instrument, and be immediately converted into a vapour so abundant and powerful that it is wonderful to see its fury and hear the noise it produces. This machine will carry a ball of a talent in weight.' It is worthy of remark, that Leonardo da Vinci, far from claiming the merit of this invention for himself, or the men of his time, attributes it to Archimedes."

the extremity, passes into a cistern (A) nearly filled with water, the end of the tube being above the level of the water. The steam from the boiler is thus conducted into the space above the water, and pressing on the water by its elastic power, forces it through the tube *d*. This, which was afterwards taken up by Kircher, in 1656, is the exact idea of De Caus's, Lord Worcester's, and of one part of Savery's engine. The steam is formed in a separate vessel from that containing the water to be raised. Porta, however, did not propose to apply it, or follow it out in any way. He also describes the rushing of water into the vacuum formed by the condensation of vapour. He thus had knowledge sufficient to have invented Savery's engine, but perhaps never turned his mind particularly to the subject.

DE CAUS.—1615.

191. Solomon De Caus was an engineer and architect to Louis XIII. of France; he was an eminent mechanic, and author of several works on practical mechanics, of which the principal, published in 1615, treats of the theory of moving forces, and describes a number of machines, and among others, one for raising water by fire—*perhaps the first instance in which steam was proposed to be used as a moving power on the large scale, in the manner in which it is now applied—namely, by its elastic force when confined.*

192. His Theorem V. is, "Water may be raised by the aid of fire higher than its own level;" in illustration of which, he gives a figure and the following description.

"The third method of raising water is by the aid of fire; whereby divers machines may be made. I shall

here give the description of one. Take a ball of copper, well soldered at every part; it must have a vent-hole to put in the water, and also a tube, which is soldered into the top of the ball, and the end approaches near to the bottom, without touching it. After filling this ball with water through the vent-hole, stop it close, and put it on the fire; then the heat striking against the said ball, will cause all the water to rise through the tube." De Caus's machine is simply Baptista Porta's cistern, without any tube conveying steam to it from a boiler, such as *a b*, (fig. 9), the cistern itself being on the fire. The tube *d* (fig. 9) may be straight or bent; that makes no material difference in the action.

193. The steam formed by the vaporization of the water, having no exit, will accumulate until it has sufficient elastic force to press on the surface of the water so strongly as to cause part of the water to ascend through the tube, and by continuing the heat thus, all the water may be expelled, as De Caus says. This experiment is exactly similar to that described in paragraph 107.

194. It has been doubted whether De Caus knew precisely the cause of the ascent of the water, or attributed it entirely (as it is certainly in part owing) to the expansion of the air above the water. But this can hardly be, as he knew so much of the nature of vapour—as that water loses when part is evaporated—that, if the vapour be confined and cooled again, it will return to the state of water, and the water will be the same in quantity; and, in describing this experiment in another place, he says, "The violence of the vapour *which causes the water to rise* proceeds from the same water, which vapour goes out through the cock after the water with great violence." "This," says Farey, "is all

that De Caus has left us on the subject of steam. De Caus distinctly mentions this power as a means of raising water, along with other plans which were in actual operation for that purpose; so that he must have considered it fit for purposes of utility, and thus, very probably, has given the hint to others. His apparatus could not be used on the large scale profitably—the water to be raised must in the first instance have been transferred by manual labour (so far as we learn from his description) into his copper boiler: nor does he seem to have thought of having a separate vessel for forming the steam; from which there would be immense loss of heat,' as *all the water to be raised* would have to be brought to the boiling point. In this respect De Caus's apparatus was inferior to that of Porta's experiment.

ENGINE OF BRANCA.—1629.

195. We now come to what appears to be the first proposal to use steam as a moving power for machinery, which was accompanied with a specific plan, and published. It is that of Giovanni Branca, an Italian engineer; and his invention is described with a drawing, in a work he published at Rome in 1629.

196. His engine was a sort of steam windmill, consisting of a boiler with its spout directed towards a wheel, so that the steam which issued from it struck forcibly against the flat vanes in its circumference, and thus caused a rotatory motion in the wheel; and the continuous motion thus produced, could easily be transmitted to any machinery connected with the wheel. He proposed to apply it to grind the materials for gunpowder, raise water by buckets, &c.; and has given

descriptions of machinery for effecting these purposes. The idea may probably have been taken from observing the force with which steam issues from the mouth of a common kettle. Bishop Wilkins, in his "Mathematical Magic," 1648, proposed a somewhat similar plan for turning a spit for roasting meat.

197. These machines, however, in the way in which they were then formed—the steam having to traverse a considerable body of air before striking on the wheel—could have very little power, as, from the low specific gravity of steam, it has little impetus, even though moving with great velocity; and, moreover, it is so rapidly condensed by cold, and so much resisted by the air, which is about twice as heavy, that it can have very little force of percussion. Accordingly, this mode of applying steam never came into practice. It has recently, however, been proposed to be introduced, under better arrangements for giving effect to it, by Mr. Pilbrow.

DISCOVERY OF THE AIR'S PRESSURE, AND INVENTION OF THE BAROMETER AND AIR-PUMP.—1642-50, &c.

198. About this time the foundations of the science of Pneumatics were laid by TORRICELLI, PASCAL, GUERICKE, BOYLE, the inventors of the air-pump, and others; at the same time the nature of pneumatical machines, as the pump, came to be understood, while new apparatus of this description was invented. The peace in England after the Restoration, and the operation of the Royal Society, then beginning to flourish, were highly favourable to scientific research and the progress of improvement in the arts. Accordingly the progress of the

steam-engine was very rapid after this period. We find WORCESTER, PAPIN, SAVERY, NEWCOMEN, following closely upon each other, each stimulated by what his predecessor had accomplished, and by the daily increasing stores of scientific knowledge and experimental skill which were placed within his reach.

WORCESTER.—1663.

199. Edward Somerset, Marquis of Worcester, published, in 1663, a small work, entitled "A Century of the Names and Scantlings of such Inventions as at present I can call to mind to have Tried and Perfected," &c. In this work, (in which, he says, the descriptions are "in such a way as may sufficiently instruct me to put any of them in practice;" thus apologising for their brevity, while he promises, in some future work, which never appeared, however, to give instructions for executing his designs,) the following passages occur, of which the first, and, there is every reason to believe, the others, refer to a steam-engine:—"LXVIII. An admirable and most forcible way to drive up water by fire, not by drawing or sucking it upwards—for that must be, as the philosopher calleth it, *intra sphœram activitatis*, which is but at such a distance. But this way hath no bounder, if the vessels be strong enough; for I have taken a piece of a whole cannon, whereof the end was burst, and filled it three quarters full of water, stopping and screwing up the broken end, as also the touch-hole, and, making a constant fire under it, within twenty-four hours it burst, and made a great crack; so that having a way to make my vessels, so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a constant fountain

stream, forty feet high; one vessel of water, rarefied by fire, driveth up forty of cold water. And a man that tends the work is but to turn two cocks, that, one vessel of water being consumed, another begins to force and refill with cold water, and so successively; the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks." This is termed a fire-water-work in the index.—Article XCVIII. "An engine so contrived that, working the *primum mobile* forward or backward, upward or downward, circularly or cornerwise, to and fro, straight, upright or downright, yet the pretended operation continueth and advanceth, none of the motions above mentioned hindering, much less stopping, the other; but, unanimously, and with harmony agreeing, they all augment and contribute strength unto the intended work and operation; and therefore I call this *a semi-omnipotent engine*, and do intend that a model thereof be buried with me." This versatile *primum mobile* must, surely, be steam; and, in article C, he speaks of a water-work, "by many years' experience and labour, so advantageously by me contrived, that a child's force bringeth up, an hundred feet high, an incredible quantity of water, even two feet diameter, so naturally, that the work will not be heard even into the next room."

200. This engine is supposed to have consisted of a boiler, having two steam tubes proceeding from it to two vessels, each of which had three apertures, one to admit the water to be raised, another the steam to raise it, and a third to let out the water to be raised—these apertures being governed by cocks, and thus alternately opened and closed. It has been questioned by some

whether he ever had constructed such an engine as he describes. Of this there can be no doubt, however, from the report of a foreigner, Cosmo de Medicis, (who saw it in operation at Vauxhall in 1663, raising water,) from the exertions his widow made to get it introduced into use, (from which we may infer, at least, that she had some ocular proof of its efficacy), and other circumstances.

201. Lord Worcester was a devoted adherent of Charles I., in whose cause he had lost his fortune and estates—being long known under the title of Lord Glamorgan. He was in exile after the ascendancy of Cromwell, till 1656, when, coming to London on some secret mission from Charles II., he was discovered, and imprisoned in the Tower, whence he was liberated at the Restoration. During his confinement, he prosecuted his mechanical studies, which were not new to him, however, as he had always had a taste for mechanics. In the dedication of his book to the Parliament, he speaks of an "unparalleled workman, both for trust and skill, Caspar Kaltoff, who hath been these five-and-thirty years as in a school under me employed." Lord Worcester was evidently a man of considerable mechanical genius and knowledge; and, had he explained clearly and published any of his numerous schemes, he might have assisted, in no small degree, in forwarding the invention of many ingenious machines, now come into use. But, instead of instructing mankind how to carry his schemes into effect, he contented himself with the glory of blazing forth a catalogue of what he could do.

202. The claims of the Marquis of Worcester to be considered the inventor of the steam-engine, have been the subject of much discussion. It is clear, from the description, that he had the idea of the elastic force of

steam, pressing water upwards in a tube, as De Caus and Porta had; indeed, it is most probable that he derived his knowledge from their works. There is every reason to believe that he had used a separate vessel for forming the steam from that which contained the water to be raised, as Porta and Kircher had; and it is probable that he introduced the water to be raised into the forcing vessel by the air's pressure; the water rushing into the vessel while filled with steam. The separate boiler was a most important addition to De Caus's plan. Moreover, he *constructed an engine*, (which no other had done,) and proclaimed its applicability, as a moving power, to a variety of purposes. But his description is so meagre and obscure that it is doubtful if it were intelligible to others at that time. It is extremely probable that Papin, who spent a long time in England, had seen the "Century;" and, although that philosopher had much precise knowledge of the nature of steam, was the inventor of the Digester, and was labouring to introduce steam in its two modes of action, (by its elastic force and its condensation,) in an engine for raising water; yet he seems never to have entered on the track which the "Century" must have pointed out *very clearly, if understood at all, till after the publication of Savery's schemes.* It is very doubtful if Worcester's descriptions conveyed anything new to those acquainted with the works of Porta, except the fact that the plan had been realised; and extremely doubtful if those not acquainted with the subject previously would (in those days) have made out what he designed. Worcester never exhibited his engine to any public body; never gave an intelligible account of it. It is not clear, from the notice in the "Century," whether he meant two forcing vessels and

one boiler (as is generally supposed); two boilers and one forcing vessel; one boiler and one forcing vessel; or two vessels with fire applied alternately to each; and it is questionable if any engine adapted to his description, on the most favourable construction, could ever have come into general use—the quantity of fuel consumed would have been so great. Indeed, the only part of Savery's engine (which embraces Worcester's) which has turned out workable, is that in which the water is raised by the atmospheric pressure—a plan which Worcester does not seem to have been aware of. In proposing the application, he made a step in advance of Porta; the separate boiler was a step in advance of De Caus. But, as he kept his plan secret, did not develop the principle, did not give directions for applying it, far less taught mankind how to work it profitably, he can have no claim to be considered the inventor of the steam-engine. All we can say of him is, that, most probably, *he devised* an improved form of De Caus's plan for raising water—acting continuously, and having a separate boiler.

GUERICKE AND HAUTEFEUILLE.—1672.

203. GUERICKE, the inventor of the air-pump, is said to have originated the idea of using the atmospheric pressure as a power by applying it to depress a piston in a cylinder beneath which a vacuum had been made; while the Abbé HAUTEFEUILLE contemplated the expansive force of gunpowder (and also of steam, according to Mr. Stuart) to raise a piston in a cylinder. There is much obscurity as to the exact nature of the projects of these two inventors; and there is reason to believe that

a diligent examination of their writings would throw light on the origin of the happy idea of applying the force of aerial bodies through the medium of a piston impelled along a cylinder.

MORLAND.—1683.

204. About the above period, Sir Samuel Morland is said to have exhibited before Louis XIV., at St. Germains, a method of raising water by means of steam; and, although there is no record extant of the particulars of his plan, it is evident, from the following extract from a work which he wrote in French, in 1683, and which is preserved in manuscript in the Harleian Collection of MSS. in the British Museum, that he was aware of that most valuable property of steam, its elastic power when confined; and must have experimented on the subject in a way which would indicate that he had actually constructed an efficient steam-engine for raising water.

"*The Principles of the New Power of Fire, invented by Chevalier Morland, in the year* 1682, *and presented to his Most Christian Majesty*, 1683.

"Water being evaporated by the force of fire, these vapours shortly acquire a greater space (about 2000 times) than the water occupied before; and, were it to be closely confined, would burst a piece of cannon. But, being regulated according to the rules of statics, and reduced by science to measure, weight, and balance, then they carry their burden peaceably, like good horses, and thus become of great use to mankind, particularly for raising water, according to the following table, which shows the number of pounds that can be raised

1800 times per hour, to six inches in height, by cylinders half filled with water, as well as the different diameters and depth of the said cylinders." These tables need not be given here.

PAPIN.—1690.

205. DENIS PAPIN, a Frenchman by birth, was Professor of Mathematics at Marburg, and author of many philosophical papers and ingenious mechanical inventions; he was driven from France by the revocation of the edict of Nantes, and came to London, where he lived for a considerable time in communication with the English men of science. He has been claimed by the French as the inventor of the steam-engine; and there are certainly grounds for assigning to him a considerable share of merit; though there is no one individual, except James Watt, who can be termed the inventor of the steam-engine. Although his apparatus was so clumsy and troublesome that it may be said to have been impracticable for use on the large scale, he was yet the first who shewed that the plan of *a piston working tight in a cylinder, and raised by boiling a little water under it, might be combined with the plan of cooling and condensing the vapour which had raised it, a vacuum thereby being formed below it, when the atmospheric pressure would force it down.* In some of his writings in the "Acta Eruditorum" of Leipsic, of 1690, he describes this engine, and says—"Water has the property, when changed into vapour, to spring like the air, and afterwards to recondense itself so well, by cold, that there remains no appearance of this force or spring." And this engine was noticed in the "London Philosophical

Transactions," for 1697, in the following words :—" A method of draining mines, where you have not the conveniency of a near river to play the aforesaid engine—[one with air-pumps and cylinders, connected by an air-pipe]—where, having touched upon the inconveniency of making a vacuum in the cylinder for this purpose with gunpowder (according to his first scheme of 1687), he proposes to procure an alternating motion by turning a small surface of water into vapour, by fire applied to the bottom of the cylinder which contains it, which vapour forces up the plug [piston] in the cylinder to a considerable height, and which (as the vapour condenses from the water cooling when the fire is taken away) descends again by the air's pressure, and is applied to raise the water out of the mine." The alternate application and removal of the fire, however, would render the machine very inconvenient—in fact, impracticable. He gives some calculations as to the power of a large engine on this plan, and suggests it as applicable to raising water, and propelling vessels against wind and tide—*so that he certainly gave the first idea of the atmospheric engine*, and must be regarded as one of the pioneers who prepared the way for the steam-engine.

206. Papin had proposed to make the pressure of the air effective as a source of moving power, by producing a vacuum in a cylinder by an air-pump, the air-pump being worked by a water-wheel; and, by tubes connected with the part where the vacuum was formed, he proposed to transfer to other machinery at a distance the power thus got from the fall of water.

207. Papin was the inventor of the SAFETY-VALVE, and of the DIGESTER, known by his name, and in use at the present time; the safety-valve was devised for the

Digester, but has now come into general use for more important purposes. In the Digester, by confining the steam, a greater heat is procured than can be had from water allowed to boil in an open vessel; and which, as he himself says, "extracted marrowy nourishing juices from bones and beef, even the oldest and hardest cow-beef; and other meats, whose horny and shrivelled fibres baffled the skill of the most experienced cooks to prepare for mastication with common boilers, when done in his Digester, came forth succulent and pulpy."

SECTION II.

SAVERY.—1698.

208. Of those who proposed to raise water by the force of steam applied directly to the water—a plan ultimately found unprofitable, and abandoned—we must award the greatest share of merit to Thomas Savery, the first who came before the public with an intelligible plan of an engine fit for practical purposes, worked by steam. All previous to Savery only threw out hints, or constructed experimental models, useless on the large scale. Branca and Papin were on totally different tracks from Savery, Worcester, and De Caus.

209. Porta's Fountain showed that confined steam might be made to raise water for a jet; De Caus proposed to apply this power to raise water for purposes of utility, giving no plan, however, except the very useless one of the apparatus used to illustrate the principle; Worcester devised, without explaining, an improvement

of the method of De Caus; and, *what these had talked about, and that obscurely too,* SAVERY DID; *adding the application of the atmospheric pressure, which none of these had thought of.* It is impossible to know how far each was original, or only improved upon a previous plan; and it is difficult to assign to each his just due of praise; but when one (Porta) points out a principle, another (De Caus) suggests its application to practice, a third (Worcester) merely proclaims (however, truly) that he knows how to apply it, and a fourth (Savery) instructs men how to apply it, the latter, surely, is entitled to the chief share of the merit.

210. Savery's engine is a very beautiful and ingenious invention. He got a patent for it in 1698, calling it an invention for "raising water, and occasioning motion to all sorts of mill-work, by the impellent force of fire:" exhibited a model before the Royal Society in 1699, and published, in 1702, a small work, called "The Miner's Friend; or, an Engine to Raise Water by Fire, Described; and the Manner of Fixing it in Mines; with an Account of the Several Uses it is applicable unto, and an Answer to the Objections made against it. Printed at London, 1702. By Thomas Savery, Gentleman." Savery was Treasurer to the Commissioners for Recovering the Sick and Wounded, and was called "Captain" by the miners—this term being often applied by them to superintendents or engineers engaged about mines.

211. Savery's engine will be understood from the annexed cut and description.

Let A, A′ represent two large copper vessels, connected with the boiler in which the steam is formed by the tubes *a a′* at the upper part; communicating at

the lower extremities by the tubes *f*, *f'*, with the lower tube *e*, the open extremity of which dips into the water to be raised, and called a *suction-pipe;* and communicating also with the upper tube *b*, called the *force-pipe*, which conveys the water to its destination.

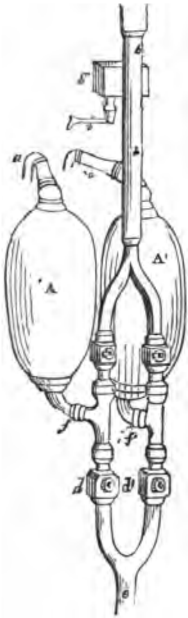

FIG. 10.

There are four valves, *c*, *c'*, *d*, *d'*, *opening upwards*—that is, which yield readily to water, pressing upwards, and allow it to *ascend*, but instantly shut by any force applied from above, and thus do not permit water to *descend* through them. These valves are most ingenious contrivances, and are essential in the construction of all machines in which liquids or gases circulate, as the air-pump, Bramah press, common water-pump, force-pump, steam-engine. They are exactly similar in action to the valves found at the apertures of the cavities in the hearts of animals, for *directing* the course of the blood.

Upon the tubes *a*, *a'*, are cocks, by which the connection between the copper vessels and the boiler can be opened and shut at pleasure. *g* is a cistern of cold water, with a tube, *i*, coming from it, which can be turned so as to pour water over either of the copper vessels.

To set the engine at work, then, steam is admitted into one of the copper vessels—say *a*. It enters, and drives out the air up the force-pipe by the valve, *c*.

When full of steam, the connection with the boiler being closed, the pipe, *i*, is brought over the vessel A, and water from the rose jet at its extremity, poured upon A. This condenses the steam in the interior, and thus forms a vacuum, or a space containing vapour of very small elastic force (131). Immediately, the water (pushed by the atmospheric pressure) rushes up in the *suction-pipe* *e*, forces open the valve *d*, and, passing through *f*, enters the vessel A, and ascends in it until it attains such a height that its own pressure, together with the elastic force of any uncondensed vapour, balance the atmospheric pressure. This is the first part of the process, exactly similar, it will be seen, to the experiment described in paragraph 40.

The vessel A, being thus filled, or nearly filled, with water, the connection between it and the boiler is again opened. The steam, issuing from the boiler, presses upon the surface of the water in A, and expels the water, which, having no other course, is forced through the valve *c*, into the force-pipe *b*, where it ascends, and is removed as required. This is the second and last part of the action of this engine, exemplifying, on the large scale, the experiment described in paragraph 107.

These two vessels were used alternately for the preceding operations—the force of steam emptying one (A) of water, by pressing the water up the force-pipe; while, in the other (A′), the vacuum was being formed, and the atmospheric pressure was filling it with water. Then, the first (A) being full of the steam which had forced out the water, the jet of water was turned upon it, while steam was admitted to press upon the water in the other (A′); the engine being thus kept in continual action, or, at least, with very little intermission.

212. There is little of interest in the boiler used for this engine. The boilers of Newcomen and Watt's engines will be described afterwards. The gauge pipes for ascertaining the quantity of water in the boiler were the invention of Savery, and he applied to his boiler the safety-valve, which was contrived by Papin for his Digester. Savery had the great merit, however, of being the first to contrive the arrangements necessary for a boiler efficient for the production, continuous emission, and regulation of steam.

Savery's engine is a very beautiful piece of mechanism; but, as it never came extensively into use, and, though afterwards improved by Desaguliers and others, was abandoned upon the appearance of Newcomen's, we shall do little more here than point out briefly the defects under which it laboured, as well as the merits of its ingenious inventor.

213. By condensing the steam, and thus giving effect to the atmospheric pressure, he raised water cheaply and easily to a height of about twenty-six feet above its level,—a clear gain of power; and, by the force of steam, he was able to elevate this water sixty-four feet higher; thus raising it, in all, by the combination of the two modes, ninety feet above its level,—certainly a great step in advance of any previous method.

214. Savery suggested the application of his engine, also, to raising water for working mills, raising water to houses for domestic purposes, and extinguishing fires, supplying cities with water, draining fens and marshes, propelling ships; but he does not appear to have drawn out or published a plan for any other application, except that of raising water. Savery died about 1717. He was much esteemed and well spoken of by his contem-

poraries. He had the satisfaction of seeing his invention applied to practice. His engine was actually applied to draining mines and raising water for gardens, as we learn from statements by himself and others.

215. But it laboured under considerable disadvantages. One of the principal of these was, that it must be erected not more than about twenty-seven or twenty-six feet above the level of the water to be raised. Were the vacuum perfect in the copper vessel, the atmospheric pressure would fill it with water, if its upper part were 33·87 feet above the water to be raised. But the vacuum is never perfect; some vapour always remains, opposing the atmospheric pressure; so much that it was found that the water could not be raised much above twenty-six feet. Here, then, was a great drawback on the engine; so near the bottom of a mine, it would be very apt to be destroyed by the water rising, especially if, from any cause, its action should be suspended for a day or two.

216. Next, engines would be required at every ninety feet, as the vessels could not bear the enormous pressure of steam (nor the boilers the heat) which would force water up to a height greater than sixty-four feet. Sixty-four feet added to the twenty-six feet which the water was raised by atmospheric pressure, make ninety. To balance the atmospheric pressure, the steam which acts on the water in the copper vessel must have an elastic force of 14·7 pounds on the square inch. Of course, it exerts no force in pressing the water up the force-pipe *till it exceeds the atmospheric pressure.* As the atmospheric pressure is equal to a column of water, 33·87 feet high, the steam must acquire the elastic force of another atmosphere—14-7 pounds per square inch more—to force the water to a height of 33·87 feet in the force-

pipe ; and 14·7 pounds more, to raise it 67·74 feet ; in all, 44·1 pounds on the square inch, an enormous pressure on the boiler and copper vessels. 14·7 pounds of this are balanced by the external atmospheric pressure, leaving a *bursting pressure* of 29·4 pounds on every square inch. Vessels and boilers could not, at that time, be made to bear safely more than this ; so that the action of the engine was limited to raising water ninety feet above its level ; hence, in mines, an engine would be required for every fifteen fathoms (ninety feet), and the whole would be suspended when one got out of order. Indeed, Mr. Savery himself recommended that the engines should not be applied for a lift of more than from sixty to eighty feet.

217. In the third place, the engines required to be small—large ones could not be made sufficiently strong —so that they raised but a small quantity of water, and, at each fifteen fathoms, several would be required.

218. Lastly, the expense of fuel for these engines was very great, from two causes:—*First*, The high pressure of the steam, which (by the table in par. 126,) would require to be of the temperature 274° Fahrenheit, in order to produce an effective pressure of 44·1 pounds on the square inch ; and, *second*, from the waste of heat in the alternate cooling and heating of the copper vessels, and in the condensation of the steam before it heated the surface of the water in the copper vessel up to its own temperature. There was also considerable risk of explosion. The power of his engine could be increased only by increasing the strength of the steam ; which greatly limited its operations.

219. The part of Savery's engine, however, in which water is raised by atmospheric pressure, has been advan-

tageously applied to raise water short distances, as twenty to twenty-five feet. In this case, the engine was made self-acting, and there was an air-valve by which the air which entered with the steam and water was blown out: this was necessary, that the vacuum might be as complete as possible. Several engines were constructed upon this plan by Mr. Rigby in Lancashire, and one in London. The water raised turned an overshot water-wheel by which the machinery was impelled in the usual way. In some situations, Savery's engine is still used with advantage. See pars. 224-6.

SECTION III.

PAPIN AND DESAGULIERS.

PAPIN.—1707.

220. In 1707, Papin published, at Cassel, a tract entitled "New Method for Raising Water by the Force of Fire." His plan was essentially the same as that of one part of Savery's—that in which the water was raised by the elastic force of the steam. The chief differences were, that the vessel in which the steam acted on the water was cylindrical, and that the steam did not come into direct contact with the water, but was separated from it by a moveable float or piston. This was a decided improvement, less steam being thereby lost by condensation. The steam, after acting on the water, was permitted to escape into the air. This engine does not possess much merit: not using the steam for making a vacuum thereby to take advantage

of the atmospheric pressure, it was decidedly inferior to Savery's, and never came into use.

221. Papin proposed this engine as a means of giving motion to a water-wheel, the water raised being made to fall upon the floats of the wheel, and turn it round in the usual manner. That the stream might be continuous, an air-vessel was interposed between the opening from which the water issued to the wheel and the receiver from which it was expelled by the steam. The air became compressed in the air-vessel, and by its elastic force in expanding again, pressed out the water in a continuous stream. The work in which this engine was described was not published till nine years after the date of Savery's patent, and in it Papin admits that he had seen the engravings of Savery's engine; so that, considering how little it is superior to the engines of De Caus and Worcester, and how far inferior to that of Savery, which certainly had the advantage in point of priority of discovery, Papin cannot, on account of *this engine*, be entitled to a place among the inventors of the steam-engine. His claims to a place in that list must rest on his first contrivances, described in paragraphs 205—7.

DESAGULIERS.—1718.

222. Desaguliers—well known as the author of a work on natural philosophy, entitled, "Course of Experimental Philosophy," published in 1743—made some valuable improvements in Savery's engine, which gave it as great efficiency, perhaps, as it was capable of, and enabled it to be employed, in some circumstances, with advantage. He thought that, by employing only one receiver, and confining the steam in the boiler while the

receiver was being filled by the atmospheric pressure, the steam would acquire such strength that, upon being turned into the receiver, now filled with water, it would press up a considerable portion of water even before the upper surface of the water had become much heated; and that thus there would be less loss of steam than in the original plan, where the steam acted without intermission, being thrown into one receiver immediately after it had pressed the water out of another. It is then weak, requires some time to recover its force, and in this time must heat to a considerable depth the stratum of water at the surface. In experimenting on the subject with a model that could be worked either with one or two receivers, it was found that one receiver could be discharged of water thrice in the same time in which two receivers could be discharged once each. The simple engine would only cost about one half of the engine with two receivers, and would do about one-third more work.' He condensed the steam by a shower of water within the receiver, instead of upon its external surface.

223. About the year 1718, Desaguliers made one of these engines for the Czar (Peter the Great), which was erected in his gardens at St. Petersburgh. This engine raised water twenty-nine feet by suction (the atmospheric pressure), and eleven feet by the force of steam—forty feet in all. With others, used for forming artificial fountains in gardens, &c., water was raised fifty-three feet in all—twenty-nine by the atmospheric pressure, twenty-four by the force of steam.

224. "Savery's engine," says Farey, "may be usefully employed for raising water to a height of thirty or thirty-five feet, which can be done principally by

suction, with only a very slight pressure for the remainder. Several small engines have been erected upon this plan; and, where the water which is raised requires to be immediately heated, they are very capital machines; because all the loss of heat being thrown into the water, warms it before it enters the boiler in which it is to be heated, so as to economise the whole of the heat—for instance, for the purpose of raising water into the evaporating boilers of a salt or alum work, or for a brewery; they are also particularly applicable for raising water for warm baths.

"A small engine of this kind was made by M. Genjembre, of Paris, in 1820, for raising water for a floating bath in the river Seine, and answered the purpose completely."

225. Desaguliers observes of his engine—in contrasting it with Newcomen's, then coming into general use—"Savery's engine, on my plan, consists of so few parts, that it comes very cheap in proportion to the water it raises, but has its limits. Newcomen's Cylinder-Engine has also its limits the other way: it must not be too small; for then it will have a great deal of friction, in proportion to the water that it raises, and will cost too much, having as many parts as the largest engines."

226. For small quantities of water to be raised moderate heights (twenty-five feet), and heated, Savery's engine, working by the atmospheric pressure only, is still advantageously employed. The first cost is trifling; and it is little liable to go out of order, or need much for repairs. There are, or were, within a recent period, several in operation in France. Engines such as this are still in use in some sugar manufactories, for raising water.

SECTION IV.

NEWCOMEN AND CAWLEY.—1705-13.

Atmospheric Engine.

227. THE disadvantages under which the engine of Savery laboured, notwithstanding the ingenious advances he made in the application of steam, were such as greatly limited the sphere of its action, and rendered it of not much value towards the great object for which steam was at first applied as a moving power—raising water from deep pits and mines.

228. In the next great improvements effected on the steam-engine, those of Newcomen and Cawley, the plans formerly in use were abandoned, and recourse was had to the method suggested by Papin's first project—viz., that of a piston pressed down in a cylinder by the atmospheric pressure, a vacuum having previously been formed below the piston by filling the space with steam, which was then condensed. That Papin's scheme gave the hint to Newcomen, there are some grounds for believing, as it is known that Dr. Hooke, who was intimately acquainted with Papin's schemes, had considerable intercourse with Newcomen on the subject. But if we allow that the hint was taken from Papin, Newcomen deserves great credit for perceiving its capabilities, after it had been abandoned by its author and others, and invention had been turned on a totally different track; and for the various adjustments by

which it was transformed from an imperfect and impracticable project, to a machine of real value to mankind. Newcomen was an ironmonger at Dartmouth, and Cawley a plumber there. They took out a patent in 1705, in which Savery was associated with them, having claimed a share in the invention on account of the principle of creating a vacuum by the condensation of steam, which formed a part of his patent engine. In 1713, they had made such progress as to have good working engines.

229. Newcomen and Cawley were the first who arranged the moving power of the engine in such a way that the steam did not act directly on the water to be raised, as in Savery's or in Papin's second engine. This, indeed, constituted the first distinct step in the application of steam as a general moving power. The water was raised by means of a common suction pump, which was worked by the engine, instead of by horses, as formerly. The engine consisted of THREE principal parts: 1st, the BOILER, a separate vessel in which the steam was generated; 2nd, the CYLINDER, in which the steam was condensed; and 3rd, the BEAM, whose movements followed the alternate admission and condensation of the steam, and which communicated the motion to the rod of the pump. The figure 11, represents, in section, Newcomen's, or the Atmospheric engine.

230. The boiler (which is seen in the accompanying diagram, below the cylinder, and marked *b*) is a large iron vessel, of proportionate strength and thickness. It is placed over a furnace, and in it the water is heated and converted into steam. From the upper part of it, a tube proceeds to a cylinder (*a*) conveying the steam

there, to be condensed. This tube has fitted to it a valve or sliding plate (y), which can be opened and shut with facility, and is called the *regulator*, or *regulating*

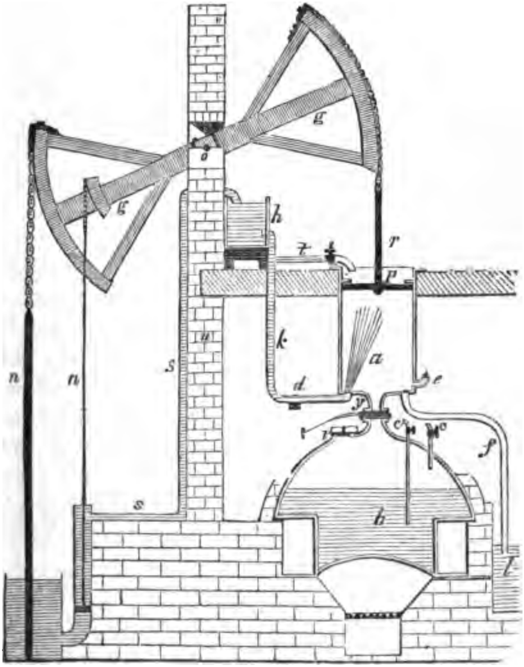

Fig. 11.

valve. By it the communication between the cylinder and boiler is opened or closed, as may be required.

231. In the boiler, two tubes, or *gauge-pipes* (c c), each furnished with a stop-cock, are placed vertically,

for the purpose of ascertaining the quantity of water in the boiler. It should contain water to the height of about two-thirds from the bottom, that is, supposing the boiler three feet deep, the water in it should be about two feet deep. One of these pipes descends into the boiler somewhat lower than one-third from the top, being more than a foot long within the boiler, supposing it to be of the size first-mentioned. The other descends to a little less than one-third from the top. In short, the gauge-pipes are made of such length that the extremity of the short one is a little above, and that of the long one a little below the proper level of the water. Accordingly, when the boiler is heated, if the water be at its proper level, on opening the cocks of the two gauge-pipes water will be discharged from the longer one, and steam from the shorter one. If the water be too low, steam will issue from both pipes; if too high, water will be discharged from both pipes. The water rises in, and is discharged from, the pipes by the elastic force of the steam which occupies the upper part of the boiler. This method of ascertaining the level of the water was proposed by Savery. It is still in use; three pipes being often used, of which the upper should give off steam, the two lower water.

232. On the side of the boiler opposite to that of the gauge-pipes, is the safety-valve (*v*), loaded to the necessary extent, but not much in this engine (about 1 lb. per square inch), as it works at a low pressure. The action of the safety-valve will be explained in the description of Watt's engine.

233. Immediately above, and communicating with the boiler by the tube between them, is the CYLINDER (*a*). In this works the PISTON, by the descent and ascent

of which the motion is procured. The piston is a solid cylinder, broad and shallow, and fitting accurately into the large cylinder; the surfaces of each being very smooth, so that the piston can slide easily up and down, but so closely fitted that no air or steam can pass between them. The cylinder is open at the top, and has three apertures below, besides the opening of the tube from the boiler. The first of these apertures, that at the left, is the mouth of the tube (*k*) which conveys the water to condense the steam. It is supplied with a valve, or stop-cock (*d*), called the injection cock, which can be opened or shut at will; and it leads from a cistern (*h*) in which there is a constant supply of cold water, brought there from the well by the action of the engine itself. This water is pumped by the rod *n*, seen attached to the beam, and the water rises to the cistern through the tube *s s*. The water thus thrown into the cylinder would gradually accumulate, along with that produced by the condensed steam, and impede the action of the piston; it is, therefore, removed by a pipe (*f*), called the eduction-pipe, leading from the second aperture, at the bottom and opposite side of the cylinder, to a cistern of water below (*l*). The eduction-pipe proceeds from the lowest part of the cylinder, and descends to a considerable depth. It has, at its lower extremity, a valve opening outwards, so that no water can return from the cistern *l*, into the eduction-pipe. Another aperture, technically called the *blowing valve*, or *snifting valve* (*e*), is situated nearly opposite to the mouth of the injection-pipe; it is supplied with a plug, or valve, opening outwards, and permitting the exit, but not the entrance, of any fluids. Through it the air is expelled before the engine is started, and also any air entering

along with the steam (158), and that may remain in the cylinder after each condensation of steam. In order effectually to expel this air, the steam requires to have an elastic force somewhat greater than the air's pressure. From the cold-water cistern (*h*), which supplies water for the purpose of condensation, a small pipe (*t*) leads to the top of the cylinder, discharging water on the piston, to preserve it air-tight, on turning the stop-cock (*i*).

234. On the large support (*u*) is placed a lever, or beam, which turns as on an axis at its centre or pivot (*o*), like the beam of a common balance. At the one extremity of it, is an arch-head, to which a chain is attached. The lower extremity of this chain is connected to the piston-rod (*r*), which, being fixed to the piston (*p*), these parts will move simultaneously up and down.

235. At the other extremity of the beam, which has a similar arch-head, another chain is attached to it; so that it is heavier and more than a balance for the piston-rod, piston, and friction of the piston in the cylinder; and, accordingly, if other forces which may tend to elevate or depress the piston be in equilibrio, the weight will draw down the end of the beam to which it is attached, and elevate the other extremity of the beam—in which position they are shown in the figure, page 123. The rod *n*, which works the pump for supplying water to the cistern, for condensing the steam, is attached to this part of the beam, near the end.

236. It now remains to describe the mode in which the engine is worked. The piston being at the top of the cylinder, and the latter full of air, the regulating-

valve (*y*) is opened, so as to admit the steam to the cylinder. The force of the air and steam push open the snifting-valve (*e*), through which the air and steam escape together. Soon, the cylinder contains steam only. When this is the case, the connection between the cylinder and boiler is closed; and the injection-cock (*d*) is opened, by which means a jet of cold water is thrown in upon the steam. This jet strikes upon the piston, and falls from it like a shower through the cylinder, and by condensing the steam, produces a vacuum in the cylinder below the piston. The atmospheric pressure, acting downwards on the upper surface of the piston, not being now resisted by air, or vapour of any considerable force, presses down the piston to the bottom of the cylinder; the atmospheric pressure on the upper surface of the piston being more than a balance for the effects of the forces tending to depress the other extremity of the beam. The piston-rod pulls down one end of the beam, and, of course, raises the other, which elevates the pump-rod, and thus lifts the water from the mine. The outer extremities of the eduction-pipe and snifting-valve, having valves or plugs that open outwards, the atmospheric pressure closes them effectually when the condensation in the interior takes place.

237. The piston, having now reached the bottom of the cylinder, the force of the atmospheric pressure (amounting to 14·7 pounds on every square inch of its upper surface) will keep it there, if no means be employed to counterbalance this pressure. But, if force be applied on the lower surface, so that the pressure on both sides of it be made equal, it will be raised again by the greater weight of the pump-rod, which, descending,

causes the piston to ascend, just as in a pair of scales, nicely adjusted, any excess of weight thrown upon one causes the other to rise. For this purpose the valve (*y*) in the tube leading from the boiler to the cylinder, is opened, and the steam, which has been accumulating and acquiring strength during the descent of the piston, rushes in, blows open the snifting-valve, aids in expelling the water through the eduction-pipe, and presses upon the lower surface of the piston. By balancing the atmospheric pressure on the surface of the piston, the elastic force of the steam gives effect to the weights attached to the other end of the beam, which will then pull down the beam at that end, and elevate the piston. The beam, piston, &c., are now in the position shown in *Fig.* 11.

By the successive repetition of these operations, the engine is steadily worked.

238. The condensed steam, and the water employed to condense it, are removed by the eduction-pike (*f*) to the cistern (*l*), from whence, by a tube passing into the boiler, and opening near the bottom, the boiler may be supplied as required. The water thus supplied to it is warm, containing the heat of the condensed steam; and it thus carries back a part of the heat which the steam conveyed from the boiler. This plan was first employed by Beighton, and is now practised in Watt's engines.

239. The condensation of the steam had, at first, been effected by cooling the cylinder externally, as in Savery's engine. The cylinder was enclosed by another cylinder, with a space between, into which space cold water was poured. Latterly, this was accomplished by the injection of cold water into the interior of the cylinder,

the water thereby coming into direct contact with the steam to be condensed—a much more efficacious method, and which is still employed. The discovery of this simple and effectual plan of condensation was the result of accident, according to Desaguliers. "One thing," says he, "is very remarkable. As they at first were working, they were surprised to see the engine go several strokes, and very quick together; when, after a search, they found a hole in the piston, which let the cold water in to condense the steam in the inside of the cylinder, whereas, before, they had always done it on the outside." This hint was followed up by the condensing pipe for injecting water into the interior of the cylinder; and thus the clumsy expedient of the double cylinder was avoided. There is no substance which answers so well for condensing steam as water. Water has a high specific heat (requires a great deal of heat to raise its temperature—see paragraph 148), and, therefore, rapidly withdraws much heat from the vapour.

240. The vacuum in this engine is produced by the condensation of steam below the piston. The steam, therefore, is not the direct cause of the power, but becomes so indirectly; furnishing, by its condensation, an easy method of forming a vacuum, which gives effect to the atmospheric pressure. As the pressure of the atmosphere, then, is the real moving power in Newcomen's Engine, it has been termed the ATMOSPHERIC ENGINE. At one stage of the action of this engine, however, the steam *is* used to give power—namely, where it is admitted to act on the lower surface of the piston when at the bottom of the cylinder, neutralising the atmospheric pressure by its elastic power, and thereby giving effect to the weight at the pump-

rod, which then raises the piston. In fact, being of an elastic force greater than that of the air's pressure, it actually does aid, though slightly, in pressing the piston upwards.

241. As the pressure of the air acts with a force equal to 14·7 pounds on the square inch, the force exerted by this engine will be in proportion to the number of square inches in the surface of the piston. But the full amount of the atmospheric pressure cannot be taken as the exact measure of the force exerted—(admitting the vacuum to be complete, which is never the case). The effect of friction between the piston and cylinder will diminish the power. Also, the weight attached to the pump-rod, in order that it may counterbalance the piston, the excess of which over the weight of the piston must be neutralised, will, to the extent of that excess, diminish the power to be procured from the descent of the piston. Further, as water, even at a low temperature, and rapidly under diminished pressure, passes into vapour, vapour will remain in the cylinder, and, by its elastic force, will tend to resist the descent of the piston, and diminish the force of the engine. It has been estimated that the elasticity of this vapour would be equal to a pressure of about four pounds per square inch, the temperature being from 140° to 160° within the cylinder. Subtracting this, and the effect of the other obstacles to the full force of the air's pressure being rendered effective, it has been estimated that a power would remain equal to about seven or eight pounds on each square inch of the surface of the piston. In general, this engine has been worked in such a manner as to raise a load of seven, or seven and a half pounds, for every square inch of the surface of the piston.

242. In this manner Newcomen's engine worked. At first there was one serious difficulty under which it laboured, in common with Savery's—the necessity of a constant attendant to open and shut the valves (the regulator-valve and injection-cock), as the piston ascended and descended; for, unless this was done with great regularity, the engine would not work with any steadiness or precision. These valves were worked by levers, which were raised by the attendant when necessary. One of them, the injection-cock, was, according to Desaguliers, worked by the engine itself. He says,—"They used to work with a buoy to the cylinder, enclosed in a pipe, which buoy rose, when the steam was strong, and opened the injection." Then he mentions that a boy, named Humphrey Potter, who attended the engine in 1713, "added (what he called *scoggan*) a catch, that the beam always opened." Potter, to save himself the trouble of constant watching, seems to have contrived to make the engine work the levers of the valves by strings attached to the beam, which, by its movements, caused the strings to open and shut the valves. Further improvements were made by Beighton, an engineer, who fixed to the beam a rod called a plug-frame, with pins or catches in it, which opened and shut the valves with great precision and regularity, so that no attendant was required for that purpose, and the engine thus worked itself. A plan similar to Beighton's was at first employed by Watt to work the valves of his engine. Making the engine itself work the valves was a very great step towards the formation of an efficient engine.

243. The engine was afterwards (1772) improved in many subordinate matters by the celebrated Smeaton. He applied his skill and scientific knowledge to deter-

mine the proper proportions of the various parts, and thus constructed engines which performed more work than any previous ones. Otherwise, no very material changes were effected upon it, excepting the adapting to it a crank and fly-wheel, to procure from the reciprocating vertical motion of the piston a continued circular motion. This was done about the year 1780.

244. The principal advantages of the atmospheric engine are—the almost unlimited extent of the power which could be commanded, as this depended solely on the range of surface of the piston ; the low degree of temperature and pressure at which the steam was produced (about 216° F., and not greater than one pound on the square inch above the atmospheric pressure), consequently there would be little risk of explosion, or of injury to the boiler from the temperature applied ; the simple mode in which the condensation was effected ; and, lastly, its self-acting power in opening and closing the valves.

245. The leading defects of Newcomen's engine were, —*First*, the alternate heating and cooling of the cylinder, during which a great quantity of steam was lost. When the cylinder has been cooled down by the cold water thrown into it for the purpose of condensing the steam, it must again be raised to the temperature of steam before any steam can remain in it. In effecting this, there must necessarily be a great loss, as the steam which effects this rise in temperature in the cylinder will be condensed in so doing, until the cylinder becomes so hot as not to condense it any more. *Secondly*, The quantity of air which rushes in during the depression of the piston by the atmospheric pressure, will, in like manner, tend also to cool the cylinder. A similar effect

results from the action of the water poured on the piston to keep it tight. The total amount of heat lost in the atmospheric engine was estimated by Watt at three times as much as was applied to the efficient action of the engine. *Lastly*, in consequence of the temperature of the cylinder in which the condensation takes place, vapour of considerable elasticity exists in it, and, by its elastic force, resists the descent of the piston. The vacuum might be made more complete by throwing in a very large quantity of injection water, and thereby cooling the cylinder more completely; but, then, there would be a very great waste of steam in heating it up again, while the great quantity of injection water required would be inconvenient. After many experiments and observations, it was considered that it was most economical to work the engine so as to have an effective pressure of seven to eight pounds on the surface of the piston; the vapour in the interior of the cylinder having an elasticity of about four pounds to the square inch.

246. The merit of Newcomen's engine lay, not in invention, but in the adoption and happy combination of contrivances already known, so as to produce an engine which *as a whole*, might be regarded as entirely new. Tredgold, speaking of Newcomen's adjustments, says, "that they produce all the difference between an efficient and an inefficient engine." Newcomen's engine was the first really efficient steam-engine—that is, the first engine which could be applied *profitably* and *safely* to the more important purposes for which such machines were required at the time of its invention. It is still occasionally ordered for situations where fuel is cheap, the first cost being comparatively small. It is fitted

with a condenser, separate from the cylinder, by which its action is much improved. In this form it has been recently re-introduced by Messrs. Seaward and Capel, in two steam-vessels, the SAPPHIRE and WONDER.

247. Though now superseded by Watt's, Newcomen's engine ought not to be forgotten. Even had it never come into use, its value, as a great step in the progress of invention—as the raw material out of which Watt constructed his admirable engine—cannot be too highly estimated. But it was a machine of great practical utility. It came into operation about 1712, and continued to be used exclusively for about sixty-two years (till 1774); and for a considerable time afterwards was much employed. For nearly a hundred years, it was the chief hydraulic machine in use for the important purposes of draining the mines, and raising water for cities; and was also used for impelling machinery.

SECTION V.

JAMES WATT, 1765.

248. THE vast improvements in the steam-engine effected by the illustrious Watt, rendered it almost a new invention; and have imperishably associated his name with it—as *the inventor* (if *one* can be named) of this great gift of genius to mankind. The changes introduced by Watt will be best described under three heads:—The Single-Acting Engine; the Expansively-Acting Engine; the Double-Acting Engine. These we shall now pro-

ceed to explain, reserving till the close of the section, a sketch of the life of their author.

I. WATT'S SINGLE-ACTING ENGINE, 1765.

249. The chief defect of the atmospheric engine was the great waste of steam, arising principally from the alternate cooling and heating of the cylinder; also, the vacuum was never complete, so that there was a considerable resistance by vapour within the cylinder to the descent of the piston. In the year 1763, while engaged in repairing a model of an atmospheric engine for the University of Glasgow,* the attention of Watt was directed to the study of the steam-engine. He performed a good many experiments on the subject, and found that, when much water was thrown in, to make a very complete vacuum, there was a great power obtained, but a great waste of fuel in heating the cylinder after being so much cooled—while, when little injection water was thrown in, vapour of considerable elasticity remained. Hence he sought for some method of *condensing the steam without cooling the cylinder*; and in the year 1765, it occurred to him "that, if a communication were opened between a cylinder containing steam, and another vessel which was exhausted of air and other fluids, the steam as an expansible fluid, would immediately rush into the empty vessel, and continue to do so until it had established an equilibrium; and, if that vessel were kept very cool by an injection or otherwise, more steam would continue to enter, until the whole was condensed." This, *a separate vessel for condensing*

* For ANDERSON, the Professor of Natural Philosophy in that University—the founder of the Andersonian Institution of Glasgow, which seems to have been the *first Mechanics' Institution.*

the steam, was Watt's grand improvement on the steam-engine.

250. By detaching the apparatus for condensation—that is, by having, separate from the cylinder, a vessel in which the steam was to be condensed, he accomplished the two grand objects of preserving the cylinder at an uniform high temperature, and of having a very complete vacuum within the cylinder, so that little resistance was offered to the descent of the piston. By preserving the cylinder constantly at the necessary temperature, no steam was wasted in raising its temperature, as in the atmospheric engine; and thus was solved the great problem in the steam-engine—*forming a vacuum without cooling the cylinder*; thereby saving all the steam which was formerly used in heating the cylinder from the condensing point up to the boiling point, after each condensation.

251. This separate vessel, called THE CONDENSER, communicates freely with the lower part of the cylinder by a tube of considerable diameter. The condenser is kept constantly cold by being immersed in a well or cistern of cold water, which is withdrawn as it becomes heated, and fresh water is supplied; and the rapid and constant condensation of the steam is insured by a jet of cold water, which continually plays into the interior of the condenser. By these means, the temperature in the interior of the condenser is kept at about 100° Fahrenheit; the vapour then having a force of only about 0·97 lbs.—less than one pound to the square inch. And, in that part of the cylinder which communicates with the condenser, the elasticity of the vapour will be equally low.

252. The injection water, the water formed by the

condensed steam, and the air which enters along with the steam (158), would soon accumulate, and fill up the condenser. This is prevented by establishing a communication between the lower part of the condenser and an AIR-PUMP, which is worked by the engine itself, withdraws the water and air which would otherwise have accumulated, and preserves the condenser always in working condition. The air-pump acts exactly on the same principle as that explained in paragraph 104.

253. In Newcomen's engine, a cooling effect was produced by the cold air following the piston in its descent. It was necessary that this should be avoided, if the cylinder were to be preserved at a uniform high temperature. Accordingly, the cylinder was closed at the top, the piston-rod moving through an air-tight and steam-tight aperture.

254. The air being thus entirely excluded, *the descent of the piston was effected by the introduction of steam above it;* and the elastic force of steam from the boiler was substituted for the atmospheric pressure in pressing down the piston. Thus the engine became really a STEAM-ENGINE. Steam was employed to form the vacuum, and steam was employed to give the force or moving power.

255. In the atmospheric engine, the cylinder was considerably reduced in temperature by the action of the surrounding air. To prevent loss of heat from this cause, Watt enclosed the working cylinder in another (called a jacket) of wood, or some substance which gave heat a slow passage through it, and thus tended to confine the heat in the cylinder.

256. From the employment of steam to press the piston down, this advantage also was gained—the engine

was not limited to one degree of force—that of the atmospheric pressure ; but its power might be increased or diminished, according to the force of the steam used to effect the motion, which, within certain limits, could be varied considerably.

257. In Newcomen's engine, the piston was kept air-tight by water poured over its surface. This was inapplicable in Watt's method, where the piston was moved by the force of steam, and the cylinder was closed above, as, if any water entered the hot cylinder, it would cool it, and condense the steam so as to diminish its force ; or at another time, pass into vapour, and retard the production of a vacuum. He, accordingly, preserved the piston air-tight by melted tallow, wax, and oil.

258. The following figure (12) illustrates the operation of the single-acting engine devised by Watt ; show-

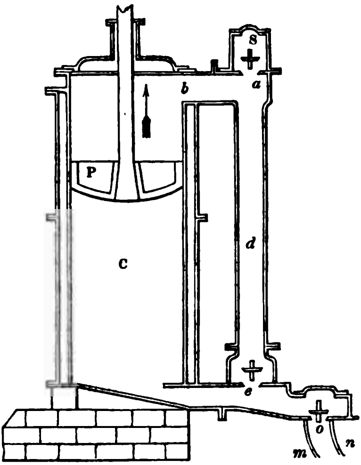

FIG. 12.

ing the cylinder and valves connected with it. The piston-rod was attached to a beam in the same manner as in Newcomen's engine. The tube *m n*, in the figure, connects the cylinder with the condenser. When the piston is at the top of the cylinder, the valve *a*, by which steam enters from the steam-pipe above, is opened, while the valve *o*, admitting steam from the lower part of the cylinder to the condenser (called the eduction-valve), is also open; but the valve *e*, connecting the upper and lower parts of the cylinder, is shut. In this state of matters, the steam below the piston rushes to the condenser (where a constant vacuum is kept up), leaving a vacuum *below* the piston, which is then pushed down by the steam entering at *a*, and pressing on its upper surface. When the piston has reached the bottom of the cylinder, the valves *a* and *o* are shut, and the valve *e* opened, by which all connection between the cylinder, condenser, and steam-pipe is closed; but the upper and lower parts of the cylinder now communicate freely, so that the upper and under surfaces of the piston are equally pressed by the steam, and it is therefore pulled upwards by the preponderance of the weight at the other end of the beam. While ascending, the piston pushes the steam above it through the passage *d* and valve *e*, to the lower part of the cylinder, so that when the piston has arrived at the top, the cylinder is filled with steam below it; then, by shutting *e* and opening *a* and *o*, the piston is pressed down by fresh steam, and a vacuum made below it, as before. The valves *a* and *o* are open, and *e* shut while the piston is descending,—the reverse when the piston is ascending. The valves were worked as in Beighton's plan, by levers acted on by catches attached to the rod of the air-pump at proper intervals.

259. In some of the first engines made by Watt, he condensed the steam by the external application of cold water to the condenser. This, however, required that the condenser should be of considerable size, while the condensation was not so effective. He soon adopted the plan of condensing by a jet of cold water thrown into the interior of the condenser,—the most rapid and efficient mode, and now almost always adopted in condensing engines.

260. The steam, when it rushes into the condenser, is immediately condensed by contact with the sides of that vessel, the outside of which is constantly surrounded by cold water, and also by the jet of cold water which is always playing in the interior of the condenser. The lower part of the condenser has an opening into the lower part of an AIR PUMP, into which the warm water from the condensed steam flows. There is a valve between the condenser and air-pump, which is of such a construction as to permit the passage of fluids from the condenser to the air-pump; but not from the air-pump to the condenser. The condenser and air-pump are surrounded with cold water, a jet of which is continually playing into the interior of the condenser. The piston of the air-pump is alternately raised and depressed by the beam of the engine, to which its rod is attached, and thus draws the fluids out of the condenser; the air-pump piston, and cylinder piston moving simultaneously in the same direction. At the side of the air-pump, is the hot-well, into which the piston of the air-pump throws the liquids which it draws from the condenser. A pump, worked by the engine, draws cold water to surround and supply the condenser. There is a short tube leading from the condenser, with a plug permitting the exit of

any fluids, but not the entrance. This is the *snifting valve.*

261. Let us now suppose that the engine is to be started (set a-going). All the valves are opened, and steam driven through the engine to expel the air, which is driven out at the snifting valve. The injection-cock, by which the surrounding water is admitted into the condenser, is then adjusted so as to pour in the necessary quantity of water into the condenser. The steam, after acting on the piston, rushes to the condenser, where it is instantly reduced to the liquid state. The condenser would soon be filled with the injection-water, condensed steam, and air which entered along with the steam, but the air-pump removes these. The valves in the air-pump piston open upwards only. Accordingly, when the piston is raised, as nothing can pass through the piston from above downwards, there is a vacuum below the piston. The valve at the bottom of the condenser being pressed by the fluids in the condenser, and opening towards the air-pump, and that pressure not being resisted in the air-pump, the valve is forced open, and the fluids rush from the condenser to the air-pump. When the piston of the air-pump descends, it tends to press the fluids back into the condenser: but, from the construction of the valve, they cannot return. Being pressed, then, by the descending piston, they force open its valves, and pass through it to the upper side of the piston, where they accumulate. When the piston ascends again, they are lifted by it, and transferred to the hot well. By this series of actions, regularly continued while the engine is at work, the fluids in the condenser are withdrawn from it, and thrown out into the hot well. The water removed from the condenser, being warm (having received much

of the heat of the condensed steam), is not altogether thrown away ; part is returned to the boiler, being conveyed, by a pump dipping into the hot well, to the cistern at the top of the feed-pipe. Thus, a part of the heat which the steam carried from the boiler is returned to it. This pump is worked by a rod from the beam of the engine. The cold water is supplied, and the whole apparatus kept cool, by water pumped by the engine, also by a rod from its beam.

262. Such were the first great improvements effected by Watt on the steam-engine ; they consisted mainly in—

1. Condensation of the steam in a separate vessel, by which the cylinder could always be maintained at a high temperature.

2. Removal of the air and water from the condenser by an air-pump.

3. Closing the cylinder above, and producing its descent by steam-pressure instead of by the air's pressure. These improvements may be said to have perfected the single-acting or pumping-engine ; at least, no modification of material consequence has since been introduced.

4. Enclosing the cylinder in a casing of wood, or other low conductor, of heat (called a jacket), to prevent it being cooled by the surrounding air.

263. These changes effected an extraordinary saving of fuel, to the extent of about three-fourths of that previously used, and thus added immensely to the power available for that great national object—the draining of mines. Watt's pumping-engines began to be introduced shortly after 1775, and he was remunerated for his invention by those who adopted it, by one-third of the saving of fuel effected by it, to be paid yearly during the

term of his patent, or redeemed by a ten-years' purchase. It has been stated that at the mine of Chacewater, in Cornwall, where three very large engines were erected, the proprietors agreed to pay 800*l.* annually for each, as a composition for the "third part of the saving in fuel effected by the substitution of Watt's for Newcomen's engine."

II. WATT'S EXPANSIVELY-ACTING ENGINE.—1769-76-82.

264. In 1769, in a letter to Dr. Small, of Birmingham, Watt developed another great principle in the application of steam, namely, *using it expansively.* He speaks of it as a method of doubling the effect of the steam; and he introduced it in an engine at his manufactory at Soho, near Birmingham, in 1776, and at other places, and took out a patent for it in 1782.

265. Although now chiefly employed as a means of economising steam, it is believed that it was originally devised by Watt as a means of remedying an inequality in the motion of the piston. In the ordinary single-acting engine, it was found that the piston moved more rapidly (with an accelerated motion) towards the end of each stroke than at the beginning, in consequence of the accumulation of its motive inertia, while the steam continued to act upon it with the same force as at first. At the commencement of the stroke, the steam has to overcome the friction between the piston and the cylinder, as well as the inertia of the mass. When it is once set in motion, its inertia (the impetus it has acquired) continues it in that state for a time, independently of the action of the steam—friction only being now to be overcome. Hence, if the steam continue to act as forcibly as at first,

it will communicate additional motion to the piston, which will, therefore, perform its stroke with an accelerated velocity. Watt cut off the supply of steam after the piston had descended a certain length (about one-third). The remainder of the descent was effected partly by the impetus the piston had already acquired, and partly *by the expansion of the steam already in the cylinder ;* for, there being little or no resistance on the other side of the piston, the steam expands and presses the piston ; its force from this source becoming less, just in proportion as the space it occupies increases—that is, just in proportion to the extent to which it moves the piston along the cylinder. Thus the motion of the piston is, to a considerable extent, equalised. The action of the steam in full strength sets it in motion—the small and decreasing force requisite to continue the motion at a uniform rate is furnished by the expansion of that steam. If the stroke of the piston, from the top to the bottom of the cylinder, be eight feet, and the farther supply of steam be cut off when the piston has descended two feet, and if the original strength of the steam be 14 lbs. per square inch on the piston, it will be 7 lbs. when the piston has descended to four feet, $4\frac{2}{3}$ lbs. when it has descended six feet, and one-fourth of its original power, or $3\frac{1}{2}$ lbs., when the piston has descended eight feet, and has arrived at the bottom of the cylinder.

266. But, what is of greatest importance, and applicable in all engines, whether high pressure or condensing, there is considerable economy of steam when it is applied in this manner. Mr. Watt states, in the specification of his patent of 1782, that, when the steam is cut off at one-fourth of its descent—" when only one-fourth of the steam necessary to fill the whole cylinder is employed—

the effect produced is more than one-half of the effect which would have been produced in filling the whole cylinder full of steam, by admitting it to enter freely above the piston during the whole course of its descent." If a certain quantity of steam produced an effect equal to 4, the effect of one-fourth of that steam acting expansively would be more than 2; or by the following table:—

If the steam be stopped at	The effect of that admitted is multiplied.
One-half	1·69 times.
One-third	2·10 „
One-fourth	2·39 „
One-eighth	3·08 „

267. In 1781, Mr. Jonathan Hornblower took out a patent for a method of using steam expansively, with two cylinders instead of one. Of these cylinders, one was smaller than the other, and was used for high-pressure steam, which was admitted above the piston to press it down: after this, a communication was opened between the lower and upper parts of the cylinder, as in Watts's single acting engine, and the piston being in equilibrium so far as the steam was concerned, was raised by the preponderance of the other end of the beam. The steam which had pressed down the piston was now below it; and was then permitted to flow into the top of the large cylinder, where it pressed down the piston, a vacuum being made beneath it by condensation; while the piston in the small cylinder was again being pressed down by fresh steam, admitted above it. Hornblower's application of the expansive principle through two cylinders, has lately come somewhat into favour, particularly in Cornwall, where the saving of steam by

using it expansively (both with single and double cylinders), has been carried to a great extent.

268. In some of the Cornish engines the steam is used of the strength of from 35 to 40 lbs. pressure on the square inch, but cut off at $\frac{1}{12}$ of the stroke. Although the greater part of the extraordinary saving proved to be attained in Cornwall is due to the carrying out the great principle of expansion—part is to be attributed to the system of registering carefully the amount of work done, by which unusual care is enforced in the management, and to the practice of protecting the cylinder, steam-pipes, and tops of the boilers, from loss of heat, by matting, saw-dust, ashes, and other non-conducting matters. It is said, that from any given quantity of fuel, the Cornish engines extract $2\frac{1}{4}$ times the duty (work done) obtained from the general average of steam-engines.

269. There has been some discussion as to the comparative claims of Watt and Hornblower, to be considered the founders of the expansive principle of action. There is no doubt that Hornblower anticipated Watt by one year in taking out the patent for it; and it has been conjectured that he made the discovery five years before he patented it—namely in 1776. But there is no doubt that Watt had discovered the principle so early as 1769—that he had engines at Soho, and others, supplied to public companies, worked on this principle, so early as about 1776-8; and when it is borne in mind how closely everything emanating from Watt's manufactory was watched, and how soon a knowledge of it was spread abroad, we cannot but consider that it is rather to Watt than to Hornblower that the world is indebted for the knowledge of the principle of the expansive use of steam.

III.—WATT'S DOUBLE-ACTING ENGINE, 1782.

270. The single-acting engine, as completed by Watt, answered admirably for the purpose of raising water, the grand object to which steam-engines were at first applied. But whenever it was found that steam furnished an efficient power for that end, men turned their minds to the discovery of the means of applying so effective a prime mover to impel machinery in general. For this purpose, the most convenient kind of motion is a rotary or circular motion, such as that of the great shaft which turns the paddle-wheels of a steam-boat. The water-wheel and windmill gave this motion directly; and a very simple machinery enabled it to be procured from animal strength. The first steam-machine on record, the Eolipile of Hero, also gave this motion in the most direct and simple manner; but it was not till the end of the eighteenth or the beginning of the nineteenth century, that Hero's machine was thought of for use on the large scale. Men's minds seemed confined to the modes in which they first saw steam-power applied to use, namely, raising water, as in Savery's, Newcomen's, and Watt's engines; and giving a reciprocating motion to the head of a beam, as in the engines of the two last.* The water-wheel being a simple and efficacious mode of procuring a rotary motion, it was proposed to use the steam-engine to raise water, which was then to be allowed to fall on the boards or buckets of a water-wheel, and turn it continuously round in the usual manner. This method was projected by Papin along with his second engine; and was used with the engine

* The Direct Rotary Engine will be noticed in a separate section.

of Newcomen; and so little progress had practical mechanics made before the time of Watt, that, so late as 1781, the celebrated engineer Smeaton, proposed to use Watt's engine for raising water to drive a corn-mill by turning a water-wheel, and maintained "that no motion communicated from the reciprocating beam of an engine can ever act with perfect equality and steadiness in producing a circular motion like the regular efflux of water in turning a water-wheel." Such were the clumsy methods to which the greatest engineers of that day had recourse for the procuring a continuous circular motion from the steam-engine. A few other devices, either very defective or very complex and troublesome, will be briefly noticed after the description of the double acting engine, several contrivances to be explained there having been used in these awkward machines.

271. In Newcomen's engine, there was only a downwards motion of the piston available as a force; the piston was pulled upwards by the clumsy expedient of a weight attached to the other end of the beam, and it gave no impulse in ascending. Watt, by the beautiful contrivance of *causing the steam to enter alternately* ABOVE *and* BELOW *the piston, and, at the same time, forming the vacuum alternately* BELOW *and* ABOVE *the piston,* gave it a moving force in ascending as well as descending, and thus a *nearly* continuous moving power was procured. Lastly, by a series of admirable inventions, he procured from the reciprocating (alternate rectilineal) motion of the piston, a *perfectly* continuous circular motion, and insured great steadiness and regularity in its action, so as to render the engine fit for the great end of impelling machinery. These—Watt's latest, and, perhaps, greatest efforts (which are rather

engine itself in the manner that will be explained afterwards: it is by the rod *v v* that it is worked. There are many kinds of valves. That shown in these figures is one of those called *slide-valves*, and is now very generally employed. By the tube *m n*, at the lower part of the valve-box *e i o u*, the steam passes to the condenser, after it has performed its office in the cylinder. The condenser had better be disregarded at present, confining our attention to what passes on in the valve and cylinder, and simply bearing in mind that there is a constant vacuum in the condenser, *and, consequently, in that part of the cylinder which communicates with it.*

274. Let us suppose, then, that the steam has just pushed the piston up to the top of the cylinder; the object now is to remove the steam which fills the cylinder, cause a vacuum in the cylinder, and admit steam *above* the piston, which steam not being resisted by any force below the piston, will easily press that body to the bottom of the cylinder. For this purpose, the valve is raised to the position shown in *Fig.* 14. In this position of the valve, the communication between the lower part of the cylinder and the condenser (by the tube *m n*) is free, and the steam rushes to the condenser, as shown by the course of the arrows; thus the vacuum is formed in the cylinder below the piston; at the same time, it will be seen that, from the construction of the valve, the passage from S to the cylinder, by its *upper aperture*, is now open, so that steam enters the cylinder above, and, exerting its elastic force on the upper surface of the piston, while there is a vacuum below it, presses it down to the bottom of the cylinder. Thus, the *downwards* motion is produced; steam being the moving power, and steam, by

its condensation, the means of forming a vacuum to give effect to this moving power.

275. The manner in which the upwards motion is effected, will be easily understood, with the aid of *Fig.* 13. The piston is there represented as it would be after being acted on by the steam with the valve in the position shown in *Fig.* 14. To raise the piston, let the valve be brought down to the position given in *Fig.* 13. Then, the steam in the cylinder above the piston will rush to the condenser, *passing out by the upper opening in the cylinder*, and through the tube of the valve, which communicates freely with the condenser, following the course shown by the arrows in the figure.

Thus, a vacuum is formed in the cylinder above the piston. This new position of the valve, at the same time admits steam from S *to the lower opening of the cylinder;* it enters, and presses up the piston to the top of the cylinder.

276. Thus, by the movements of the valve, steam is admitted alternately on each side of the piston ; while the steam on the other side is removed by a communication being at the same time opened with the condenser ; and, by this beautiful adjustment, a steady alternate rectilinear motion is produced. We cannot help remarking here how perfectly the action of the steam, in producing motion of the same body alternately, in two directly opposite directions, illustrates Worcester's graphic description of the powers of this versatile agent.

Connected with this part of the engine, there are four contrivances—the *Indicator*, the *Condenser Gauge*, the *Eccentric Rod*, and the *Governor*, which will be most conveniently described at present.

277. THE INDICATOR.—This extremely useful piece

of apparatus is attached to the cylinder, and points out the state of the steam in the cylinder, showing the difference between the strength of the steam in the boiler and that in the cylinder—between the vacuum in the condenser, and that in the cylinder.

The indicator consists of a brass cylinder attached by a tube to the grease cock of the steam-cylinder. There is a stopcock on this tube, by opening which and the grease cock, the indicator cylinder is open to the steam-cylinder. The indicator cylinder contains a piston which works in it, and the motion of which is resisted by a spring, which yields the tenth of an inch for every pound of pressure applied to the indicator piston. An index is attached to the piston-rod, which, showing the situation of the piston, indicates at the same time, the degree in which the spring is compressed. By means of a pencil attached to the indicator's piston-rod, and a cylinder with a card or piece of drawing paper round it, which is connected with the indicator cylinder, *the motions and successive situations of the indicator piston are represented by lines drawn on the card by this pencil.* The cylinder with the paper has a connection with some moving part of the engine (as a radius bar) which causes it (the paper cylinder) to revolve *once* during *one* stroke of the steam piston.

When the steam is above the piston, it forces up the indicator piston, and the line drawn on the paper shows the height of that piston, and consequently the strength of the steam at different parts of the stroke. When the steam is below, and the vacuum above the piston, the pressure of the air on the indicator piston depresses it, in proportion to the degree of exhaustion in the cylinder, and thus indicates the extent of the vacuum there.

It is found by the indicator that the steam attains its maximum effect almost immediately on entering the cylinder; while the condensation does not reach its greatest extent, until some little time after the communication has been opened between the cylinder and condenser. Hence, the eduction pipes require to be much larger and more capacious than the induction or steam pipes.

278. CONDENSER GAUGE.—The object of the condenser gauge is to show the elastic force of any vapour that may remain in the condenser—to judge of the extent of the condensation there. As water retains the state of vapour at very low temperatures, *some* vapour will exist in the condenser, however cool; and its elastic force may be judged of in the usual manner, by communication with a bent tube containing mercury, open to the air at one end and to the condenser at the other. If the vacuum were perfect, there would be a difference of 29·8 or thirty inches in height between the mercury in the tube open to the air, and that in the other extremity open to the condenser, the mercury in the latter being pressed up by the atmospheric pressure on the surface of the liquid in the other limb of the tube. But the vapour in the condenser resisting the atmospheric pressure, depresses this column a little, reducing it to about 26 to 28 inches in general. The temperature of the vapour in the condenser is generally about 100° Fahrenheit, at which it has an elastic force of about two inches of mercury.

279. ECCENTRIC ROD.—The object of this rod is to work the valve—to communicate an alternate rectilinear motion to the rod *v v*, so that the valve may be made to assume alternately the positions shown in *Figures* 13 and 14. This is done in the following manner. The

axis on which the fly-wheel turns, has a continued circular motion. By means of the eccentric rod, and one or two bent levers interposed between this axis and the rod of the slide-valve, the latter is moved as required. The construction of the eccentric rod and its motions will be understood from the following figures (15, 16.) Let C in both figures be the rod or axis which by its revolution gives motion to the eccentric rod (*e r u o*). C, although revolving, always remains in the same point. This is shown in the two positions of the eccentric rod in the figures, by C being in the same perpendicular line. To C is fixed a disk or plate (*a b d*), which revolves along with C, *with its centre c at some distance from the point* C *on which it turns*. Hence the

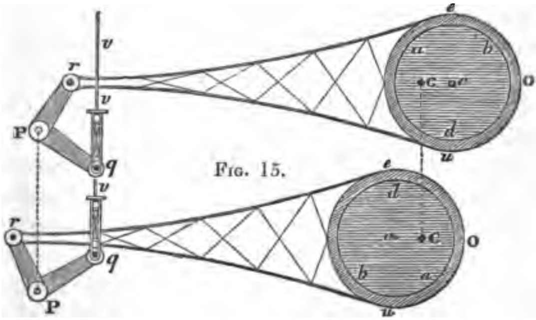

Fig. 15.

Fig. 16.

name eccentric (*ex*, out of, the centre.) Fitting close to this plate, there is a ring (*e o u*), within which the plate has free motion, but fitting closely to each other. The rods *e r*, *r u*, fixed to the ring, are attached to the free end of one limb of the bent lever *r* P *q*: to the extremity (*q*) of the other limb, the rod of the valve *v v*

is attached. P is the fixed point (or rather rod, for the two arms of the lever are attached to different points of one rod, necessarily represented as *one* in the figure), on which the lever turns. That it is fixed, is shown by P in both figures being in one perpendicular line—the dotted line. It is clear that, when the plate *a b d* makes a half revolution from the position shown in *Fig.* 15, it will carry the eccentric rod and levers into the position shown in *Fig.* 16. This raises the end of the lever (*q*) to which the valve-rod is attached, and therefore elevates the rod. When it has completed another half revolution, the end (*q*) of the lever will be depressed, and will pull down the valve-rod along with it. The action will be very easily understood, if it be kept in view that C and P are fixed points.

280. This apparatus is not always so simple as represented in the figure, another lever being often interposed. But the action is perfectly the same, and, however complex, will be understood at once by any one who has studied the preceding figure.

281. The use of the part (*q v*) interposed between the end of the lever and the end of the valve-rod, is to adapt the circular motion of the end of the lever to the rectilinear motion of the valve-rod. This will be explained more particularly under the head PARALLEL MOTION: (see par. 292.) In steamboat engines the motion of the valve is brought about by machinery very closely resembling that shown in the above figure. In some engines the eccentric rod is applied to many other purposes besides working the valves. It is applicable wherever an alternate rectilinear motion is required, and the motion from which it can be most conveniently procured, is a continuous circular motion.

282. In Watt's first engines, the valves were worked as in Beighton's plan. Catches attached to the rod of the air pump, were so adjusted as to raise at proper times levers which opened and shut the valves.

283. GOVERNOR.—The object of the governor is to determine the quantity of steam to enter the cylinder, and thereby regulate the action of the engine, should it happen to work too vigorously, either from the increased activity of the fire or diminished resistance ; or to work languidly from the opposite causes. The *throttle valve* (*t*), in the steam-pipe *t* S, *Fig.* 13, regulates the quantity of steam which passes through, by the degree in which it lies parallel to or across the tube ; and it is by the governor that the direction of this valve is determined.

284. The motion of the governor is derived, in the first instance, from the engine itself, by a cord, strap, or chain *c p w*, running round the axis of the fly-wheel, and communicating its motion to a pulley, *p*, *Fig.* 17. This figure represents the governor. The pulley is fixed to the upright rod or spindle (*e w*). To the spindle, two balls are attached (*b b*), of course revolving with the spindle, but having also a joint by which they can be raised or depressed, so as to recede from or approach the spindle. The rods of the balls are connected with levers (*o o*), which move freely on other levers (*i i*), which, at

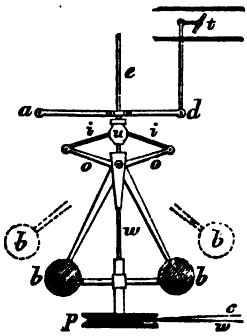

FIG. 17.

their other extremities, are attached to a ring of metal (*u*), capable of free motion up and down the spindle. Above this ring is another lever (*a d*), fixed at *a*, and fitting loosely round the spindle *e w;* and from the extremity (*d*) of this lever, proceeds a bent lever (*d t*), at the extremity of which is the *throttle valve* of the steam-pipe. Now, when the axis of the fly-wheel is moving with too great velocity, its increased rate of motion will of course be communicated to the spindle of the governor. It will revolve more rapidly, and the balls attached to it will (from their increased centrifugal force) fly out further from the spindle. The effect of this will be to depress the levers *o o*, when the levers *i i* and the ring *u* will also fall. Hence the lever *a d* will slip a little down the spindle (or be pulled down if attached to the ring *u*); and this, from the construction of the bent lever *d t*, will bring the *throttle valve t* more across the steam-pipe, so as to contract it; less steam will now enter the cylinder, and the action of the engine will be moderated. Should the engine be working too slow, the balls would fall, the throttle valve be opened, and more steam admitted.

285. This regulator or governor was used by millers to regulate the rate of motion of the grind-stones, and adapted by Watt for the purpose above described. In steamboat engines, the levers of the throttle valve are under the immediate control of the engine-man, who acts as the governor.

286. Having described the parts of the engine immediately connected with the course of the steam, we shall now quit the steam, and proceed to consider those parts of the engine which are concerned in adjusting the motion alone. These are chiefly THREE—the BEAM, the

CRANK, and the FLY-WHEEL. In all of Watt's engines, the beam was used. In those to be applied to move machinery, the crank and fly-wheel were adopted by him.

287. THE BEAM.—The piston-rod is the instrument by which the motion is transmitted *from the cylinder*. Watt transferred the motion, in the first instance, to a BEAM, similar to that employed by Newcomen. But, for an engine such as that just described (the double acting steam-engine), where the piston has to communicate motion both ways, *to push up* as well as *to pull down* the beam, the connection of the ends of the beam and piston, by a flexible chain, would not answer. The chain would not communicate an impulse; it was therefore necessary that the piston should be connected immediately to the end of the beam, or that some rigid inflexible bar should be interposed. Here, a difficulty presents itself. The end of the piston-rod must move in a straight line; otherwise, the aperture through which it works in the top of the cylinder, must be wider than the diameter of the piston-rod, to allow for its play sideways. But the piston-rod must move air-tight through this aperture. The head of the beam on the other hand, describes a segment of a circle. These motions must be adjusted, so that the beam shall not press the piston-rod outwards in the first half of its descent—so that there shall be no lateral strain on the piston-rod.

288. PARALLEL MOTION.—This was effected by Watt, in the manner which will be understood from the following figure (18).

Let R be the head of the piston-rod P R; B the end of the beam. B describes a segment of a circle, and R

moves vertically up and down. These motions are adjusted so as to harmonise with each other by the following contrivance. Let a fixed point (F) be taken,

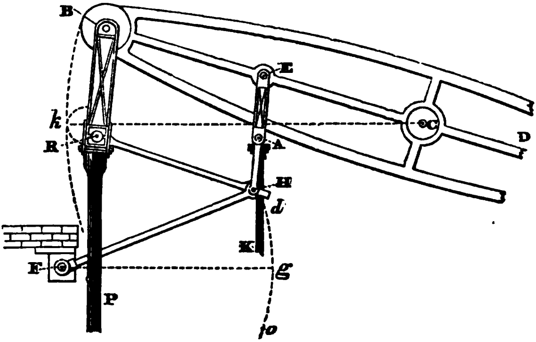

FIG. 18.

as near as possible to the line in which the piston-rod moves. From the points B and E of the beam, let inflexible bars B R and E H hang down, moving freely on pivots at B and E. Let the extremities R and H of these bars be connected by a transverse rod R H; and let another rod pass from H to F—all having free motion on pivots at both extremities. Let the head of the piston-rod be attached to the pivot at R—then it will have a motion nearly vertical, at least without any considerable strain from the *outward* motion of the beam during the first half of its *descent* and the first half of its *ascent*, or from its *inward* motion during the latter half of its *descent* and the latter half of its *ascent*; for while in the descent of the beam to the horizontal position from that shown in the figure, the bar B R is pushed outwards by the beam (as will be seen from the

inclination of the bar, and from considering the motion of the point B, moving on the centre C), the rod R H counteracts this, by pulling the point R in an opposite direction, the end H of the rod R H being preserved at a proper distance from the required line of motion of the piston-rod, by the rod H F, which, fixed at F, describes with its extremity H, the arc *d g*, which bends inwards as much as the arc described by B bends outwards, and thus preserves the point R moving almost vertically. When the beam has come to the horizontal position (shown by the dotted line C *k*), the bar B R will then hang perpendicularly, and the rod F H will also be horizontal, as in the dotted line F *g*. In the latter part of its descent, the point B will evidently tend *inwards*. and tend to push inwards the head R of the piston-rod; but the rod F H then tends *outwards* (describing the arc *g o*); and thus (by the rod R H) resists the inwards thrust of the beam.

289. In ascending, similar adjustments take place between the beam and the piston-rod, and the latter is preserved nearly vertical, and all strain in one direction neutralised by the opposite action of the rod R H.

290. The same machinery serves to give a vertical motion to the rod of the air pump A K, which is worked by the beam. The extremity A of the air pump rod is attached to the middle point of the bar E H. If this bar connect the free extremities of two rods F H and C E, being attached to them by pivots; if these rods be of such length that, when horizontal, E H be perpendicular (or nearly so) to both; then, if these rods be moved up and down on pivots or centres (F and C), the middle point (A) of the connecting bar (E H) will move in a direction nearly vertical (truly a peculiar curve of a

high order, but practically not far from the perpendicular), while the extremities of the bar describe each a segment of a circle. To the point A, the air-pump rod is attached; and, while the extremities E and A incline alternately to the right and left, the point A, about which they oscillate, preserves a vertical motion.

291. It has been said that Watt first conceived the idea of attaching the head of the piston-rod to the point A, (E being in this case the end of the beam,) but found it more convenient—and to answer equally well—to use the point A for the pump-rod, attach it by a bar to a point between the centre and extremity of the beam, and by the bar B R, parallel to E H, and the rod H R, to give R a motion parallel to that of A; whence, as well as from the bars R B, E H, being parallel, this beautiful piece of mechanism has acquired the name of PARALLEL MOTION.

292. The above description of the adjustment of the motions of the beam and piston-rod, will suggest the necessity of the bar *q v*, interposed between the extremity of the valve-rod and the lever by which it is worked. (*Fig.* 15, page 155.) The end *q* of the lever describes a curve—*v* must move in a straight line. The bar *q v* oscillates backwards and forwards; and, while it communicates the impulse, prevents any considerable strain from the difference of the motions.

293. The parallel motion is sometimes dispensed with, by causing the head of the piston-rod to move in a groove or slide. An example of this will be given under the account of STEAM-BOAT ENGINES and DIRECT ACTION ENGINES.

294. THE CRANK.—The object of the crank is to procure from the reciprocating motion of the end of the

beam, that motion which is required for all sorts of machinery, for propelling steamboats and steam-carriages —a CONTINUED CIRCULAR MOTION. The crank and fly-wheel had long been used in the spinning-wheel and turning-lathe, for procuring a circular motion from the rectilinear motion of the foot, in its pressure on the treadle. The following figure (19), which will be easily understood, will illustrate the crank. Let E be the extremity of the beam, moving up and down in an arc of a circle, and *c* the rod, shaft, or axis, to which it is desired to communicate a regular continuous circular motion. Let a short bar (*c* B) proceed from the rod to be turned, and play upon a pivot (B), to which is attached, playing also freely upon it, a long bar or rod (E B), the other extremity of which turns on a pivot (E), at the end of the beam. It will easily be understood how the rod (E B), descending as the beam descends, and moving up along with it, will turn round the crank (B *c*), the extremity B describing a circle round *c*, which is necessarily turned along with the crank B D, to which it is immoveably fixed. The rod (E B) descends on one side of the centre (*c*), and ascends on the other side ; and thus, from the alternate rise and fall of the beam, a continuous rotatory motion is communicated to the axis *c*.

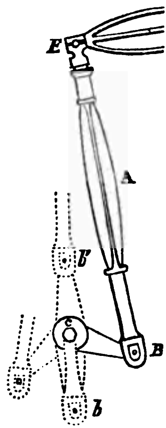

FIG. 19.

295. There are two points in the revolution of the crank, called dead-points, where the engine has no action upon the crank, in turning

it, but pulls or presses it vertically, the crank being in such a position that it has no tendency to turn the axis. This will be readily understood from the figure. When the end of the beam is at its highest elevation, the rod hangs perpendicularly from it, *and the crank is in the same line* (in the position *c b'*, *Fig.* 19). The beam then tends to *depress* the crank and axis, but not to *turn* either. When the end of the beam is at its lowest point, the rod hangs perpendicularly from it, and *the crank then also is in a line with the rod* (in the position *c b*, *Fig.* 19). In this position also, the beam has no action in *turning* the crank or axis; but tends to pull them straight upwards. These are the two dead-points, or critical points. From these it is carried by the inertia of the crank; that is, by the tendency a body in motion has to continue moving until some sufficient resistance checks it. Every one knows that a body in motion (as a ship or carriage), does not stop the moment the impelling force ceases,—that it continues for a little, until friction, and the resistance of the air or water, gradually overcome it. In like manner, the motion acquired by the crank before it reaches the critical points, carries it beyond them, and when a very little past them, the beam resumes its usual action. The fly-wheel also aids in carrying the crank past the dead-points.

296. Although, however, the crank is carried easily by its inertia out of the critical situations, it exerts little or no force in turning the axis while in them. The crank moves slowly when about the critical points—more rapidly in the other situations, where the beam acts directly in turning it. Hence, an inequality in the motion of the axis, and any machinery which derives its motion from it. This is remedied by the fly-wheel.

297. THE FLY-WHEEL.—In applying the steam-engine to drive machinery, it is particularly necessary that the engine should work with a perfectly steady and uniform force; that there should be no irregularities in its action; or, if unavoidable, that these should be transmitted very gradually to the machinery; that there should be no abrupt transition from slow to quick, or the reverse. Such inequalities might arise from the diminution in the impetus of the crank at the two critical points, from changes to a certain extent unavoidable in the strength of the fire, or from a change in the resistance given by the machinery from some of the work being stopped, or more work thrown on. By means of the governor and the throttle-valve, the adjustments of the feed-pipe and the damper, a proper proportion is preserved between the supply of steam and the demands of the engine. *But these require a little time to come to an adjustment*; and, before that could be effected, in case of any sudden change, considerable injury might be done.

298. This is prevented by the action of the FLY-WHEEL. This is a large wheel with a heavy rim, formed of iron, and fixed to the axis which the crank turns, and revolving along with it. By its weight, it acts as a drag on the engine, should it have a tendency to go too fast; and, by the great impetus which its weight gives to it, carries on the machinery with the usual, or a *gradually* decreasing force, when the proportion of the resistance to the power becomes augmented, and the engine has a tendency to move slowly. The fly-wheel equalises, by its weight, any irregularities on either side, being a sort of reservoir of power, which it absorbs, and distributes gradually when the power is too great, and restores and

gives out when the power is diminished or the resistance increased. A heavy body of this kind attached to the axis, and interposed between the power and the resistance, by its inertia slow to move, and equally slow to cease moving or to change its rate of motion, is of the greatest value in equalising the motion in those engines which are applied to move machinery. BUCKLE'S PNEUMATIC EQUALISER is another contrivance for causing an engine to move with a uniform force. It consists of a piston moving in a cylinder closed below, but open above to the air's pressure, and by simple contrivances connected to the engine. When, from any cause, the engine has an excess of force, the piston is pushed up against the air's pressure. When the force of the engine is diminished, the atmospheric pressure pushes down the piston, and restores to the engine the force which had previously pushed it up.

299. Having now examined in detail the several parts of the double-acting engines, we shall examine them in connection, as exhibited in the following figure representing a modern double-acting steam-engine for driving machinery.

300. At the left is seen the great steam tube, admitting steam to the cylinder (C *y*), by the throttle-valve (*t*); and a smaller tube, conveying warmed water to the boiler, from the hot well (H). The piston is at the top of the cylinder, the end of the beam connected with the piston in its most elevated position, and the air-pump piston also at its highest elevation. The fixed point for the parallel motion is F, the rod proceeding from which keeps the inner extremity of the rod B at a proper distance from the head of the piston-rod. The hot-water pump is worked by the rod W, and the cold-

water pump by the rod O L; frequently both are worked by one rod from the beam. The rod which propels the crank is in its lowest position, hanging quite perpendicularly. The spindle of the governor has motion communicated to it by a cord or strap from the axis, shown

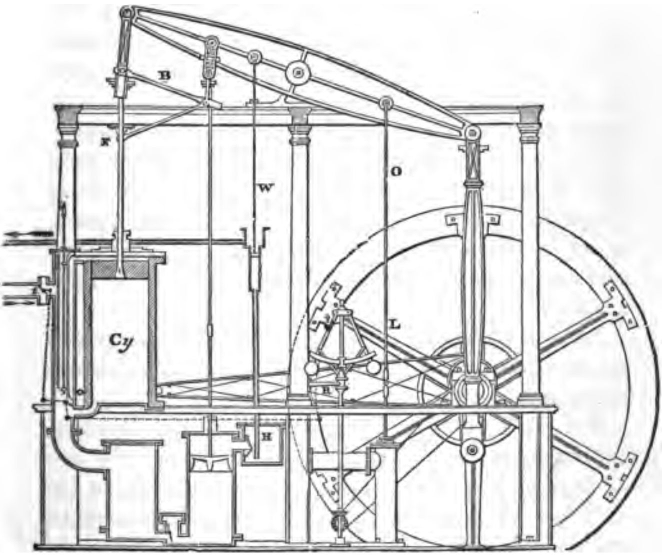

FIG. 20.

by the double line. This turns a perpendicular bevelled wheel, acting upon another, which is horizontal, to the centre of which the spindle is attached. The governor here differs slightly in construction from that represented in *Fig.* 17, page 157, but is quite the same in principle. It acts upon the lever R, which will be observed, by

tracing the course of the dotted lines connected with it, to act upon the throttle-valve *t*. The eccentric rod is seen passing from the axis, behind the piston, to raise or lower the slide-valve. The valve and rod are similar in construction and action to those shown in *Figures* 13, 14, 15, 16. The large and heavy FLY-WHEEL attached to the shaft, to equalise the motion when the force of the steam is increased or diminished, or the work to be done is increased or diminished, is observed at the right. By an endless cord or belt, moving round the shaft, and round the rod of any machinery, the motion is transmitted to the machinery. When the machinery consists of a number of separate parts, which work independently, and require to be frequently stopped, or set in action at different times, belts or straps are provided for each, which can be slipped off or on in a moment.

Such was Watt's greatest invention—and perhaps the greatest mechanical invention ever made—the double-acting steam-engine.

301. Although the *single-acting engine* and the *atmospheric engine* had been adapted for machinery by the addition of a crank and fly-wheel, these were found insufficient to give that smoothness and uniformity of motion requisite. This was from the piston acting only in its descent, and a very heavy fly-wheel or weight being necessary to carry the crank round during the intermission of the power. But still the atmospheric engine was in considerable use for this purpose. Watt, in 1778, turned his attention to the subject, and, in 1782, he took out a patent for the DOUBLE-ACTING ENGINE. He says—"Having made my reciprocating engines very regular in their movements, I considered how to produce

rotative motions from them, in the best manner; and, amongst various schemes which were subjected to trial, or which passed through my mind, none appeared so likely to answer the purposes as the application of the crank, in the manner of the common turning lathe (an invention of great merit, of which the humble inventor, and even its era, are unknown); but, as the rotative motion is produced in that machine by the impulse given to the crank in the descent of the foot only, it requires to be continued in its ascent by the energy of the wheel, which acts as a fly; being unwilling to load my engine with a fly-wheel heavy enough to continue the motion during the ascent of the piston (or with a fly-wheel heavy enough to equalise the motion, even if a counterweight were employed to act during that ascent), I proposed to employ two engines, acting upon two cranks, fixed upon the same axis, at an angle of 120° to one another, and a weight placed upon the circumference of the fly-wheel, at the same angle to each of the cranks, by which means the motion might be rendered nearly equal, and only a very light fly-wheel would be requisite."

These, and other contrivances for double engines, have been superseded by Watt's beautiful invention—the Double-Acting Single Cylinder Engine.

302. "The method," says Farey, "of combining two cylinders to act with two cranks formed upon the same axis, has since been brought into use, with great advantage, in the modern engines, for propelling carriages, and for steamboats. It is an excellent plan, and has also been applied to turnmills." The atmospheric engine was also applied in this way, according to the project of Mr. Francis Thompson—two cylinders, each

with a piston, being employed. The pistons had one common rod, the cylinders being placed one over the other: the air acted alternately on them, pushing one piston down, and the other up, the cylinder of the latter being *inverted*—closed above and open below. Thus a double action was given to the piston. An engine of this kind was erected at Arnold, in Nottinghamshire, about the end of last century, for a spinning mill.

303. Watt was anticipated in his design of taking out a patent for the use of the crank to obtain a circular motion from the reciprocating motion of the beam, so

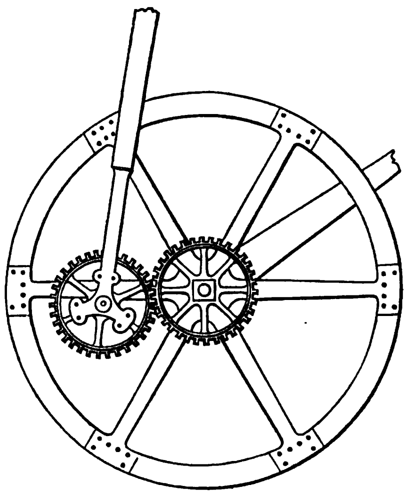

FIG. 21.

that he was prohibited from the use of the crank for his double-acting engine at first. With that extraor-

dinary fertility of invention which characterised him, he produced the SUN AND PLANET WHEEL as a substitute. The nature of this contrivance will readily be understood from *Fig.* 21.

304. We may here recapitulate the leading contributions of Watt to the steam-engine :—

1. The condensation of the steam in a vessel distinct from the cylinder, which was thereby always preserved hot.

2. Removal of the air and water from the condenser by an air-pump.

3. Producing the movement by the force of steam instead of by the air's pressure.

4. Cutting off the steam before the completion of the stroke, thus saving steam and equalising the motion of the piston (expansively-acting engine).

5. Giving the piston an impulse or moving power in ascending as well as in descending (double-acting engine), and invention of the parallel motion.

6. Converting the alternate rectilineal (reciprocating) motion of the piston into a continuous circular motion by the Sun and Planet Wheel or Crank, so as to adapt the engine for impelling machinery.

7. Application of the governor and throttle-valve, &c., to render the motion smooth and uniform.

305. Having now concluded our account of the chief of the inventions and improvements by Watt, and these being such as to give to the *fire-engine* a power and extent of usefulness quite unexampled, to confer on his engine the peculiar distinction which it still retains, of being THE STEAM-ENGINE, we shall present a short sketch of the life of its illustrious author, who stands forth as one of the brightest examples of that which

is above all entitled to honour and respect—talent successfully applied to produce works of utility to mankind.

MEMOIR OF WATT.

306. JAMES WATT was born at Greenock, in the West of Scotland, in the year 1736. His father was a block-maker and ship-chandler there, and was much respected by his townsmen. Watt was educated at the Grammar-school of Greenock. After being some time with a mathematical instrument maker, he went to London in 1754, and there continued the same profession. About 1758, he returned to Scotland, and commenced business on his own account in Glasgow. The professors of the University there, being anxious to promote the art of making philosophical instruments, appointed Watt philosophical instrument maker to the University, and gave him apartments there, for carrying on his business. "My attention was first directed," says Watt, "in 1759, to the subject of steam-engines by Dr. Robinson, then a student in the University of Glasgow, and nearly of my own age. Robinson at that time threw out the idea of applying the power of the steam-engine to the moving of wheel-carriages, and to other purposes; but the scheme was not matured, and was soon abandoned on his going abroad." He then states that, in 1761 and 1762, he made some experiments on the force of steam in a Papin's Digester, and with it, and a syringe with a solid piston, formed a species of steam-engine (very like Leopold's), which he found could be made workable; but abandoned it, from the danger of bursting the boiler and the difficulty of making the joints tight;

and also that a great part of the power of the steam would be lost, because no vacuum was formed to assist the descent of the piston.

307. In the winter 1763-4, his attention was again directed to the steam-engine, from being engaged in repairing a model of Newcomen's engine, used in the class of Natural Philosophy in the University. In examining its action, after being put in order, he found that a very great quantity of steam was required for it; and this leading to further inquiries and experiments, he found that the waste arose from the alternate heating and cooling of the cylinder. In 1765, the grand idea occurred to him of preserving the cylinder at a uniform high temperature, and condensing the steam by opening a communication between the cylinder and a separate vessel always kept cool, termed a condenser. He constructed some models upon this plan, and took out a patent in 1769. About that time, he formed a connection with Dr. Roebuck, of the Carron iron-works, and who had rented large coal-works at Kinneal. The first of his engines was erected there. It had a cylinder of eighteen inches diameter; and was altered and modified in various ways, until it was advanced to a state of considerable perfection. In consequence of embarrassments in his business, Dr. Roebuck, in 1773, transferred his interest in Mr. Watt's projects to Mr. Boulton, of the Soho manufactory, at Birmingham.

308. In consequence of the time and expense necessary to bring the engine to a tolerable working condition, and the obstacles to their introduction, from apathy or prejudice, Mr. Watt found that the term of his patent would expire before he could have reaped any considerable advantage from it, or even been remunerated for

the time and money spent in completing his project. He therefore applied to Parliament for an extension of his privilege, which was granted in an act passed in 1775, whereby the exclusive right of "making, constructing, and selling the said engines within the kingdom of Great Britain and his Majesty's colonies and plantations abroad," was vested in James Watt, his executors, &c., for twenty-five years from the passing of the act—to 1800. Thus secured in the just reward of his genius and application, and aided by the capital, skill, and activity of Boulton, Watt settled at Birmingham, and constructed and brought into use engines, by which immense savings in fuel were effected wherever they were applied. By 1778, he had many of his engines at work; and, after their economy and superior efficacy became known, they were universally used wherever new engines were required, and were frequently substituted for the old ones, even where these were still in fair working condition. Watt was continually introducing important improvements, so that his later constructed engines were greatly superior. In 1778, he introduced the expansively-acting steam-engine; and, in 1782, he took out a patent for the last great change he effected on the engine,—giving it the double-acting power. Many other improvements were introduced from time to time, but this was the greatest; as it adapted the engine for the important object of impelling machinery.

309. At the expiry of his parliamentary patent in 1800, Mr. Watt withdrew from business, and passed the remainder of his life in retirement. He was a man of great general information, and of a cultivated mind. He did not confine his attention to mechanics, but took considerable interest in the study of general literature and

philosophy. He was always deeply interested in antiquarian researches; and the fine arts also received much of his attention. In private life he was much esteemed and beloved. In 1808 he was chosen a member of the National Institute of France. The steam-engine was not Watt's only contribution to the arts. He invented that very useful contrivance, the *copying-press*, for which he took a patent in 1780. He revived and introduced *heating by steam*. He introduced into this country the beautiful French method of *bleaching by chlorine*. And, in 1783, on hearing of the then new experiment of the deposition of water on a cold surface held over burning hydrogen, he suggested the true explanation,—the formation of water by the union of the hydrogen with the oxygen,—in a letter to Dr. Priestley, so that he, undoubtedly, without communication with others,—discovered and made known amongst scientific men, the true theory of the composition of water.

310. Mr. Watt died in 1819, at his seat at Heathfield, near Birmingham, at the advanced age of eighty-three. After his death, public meetings were held in almost every considerable city in the kingdom, at which the leading men of the place of all parties, vied with each other in the eloquence and warmth of their eulogiums on the truly illustrious deceased; and all united in an anxious wish to pay to his memory the tribute of a nation's gratitude and respect.

311. If we judge of Watt by the talent displayed in the construction of his steam-engine, he must be placed in the foremost rank of inventors. When we consider the perfect state to which he brought the engine, the many beautiful contrivances he introduced to economise the power and extend its applications, the rude materials

and limited knowledge there then were to work upon, and that eighty years, at a time when science and art have been making rapid advances, have added little to the engine as he produced it, Watt must be allowed to hold a very high place among those distinguished for mechanical genius.

312. If we estimate him by the effects which have flowed from his invention, he stands second only to the inventor of printing. This may not be a proper ground on which to form an opinion of his genius ; but it should not, or at least will not, be forgot, in paying a tribute of gratitude to his memory. The steam-engine has done and will do more to improve the condition of mankind, than any other discovery since that of printing. In considering the steam-engine, we cannot confine ourselves to a mere description of its construction and principles of action. We cannot look upon it merely as a beautiful piece of mechanism, only the action of which interests us. It is something more than the best contrivance for producing motion. It has a deeper and broader interest for mankind. By its extensive and important applications, it may be said to be a great moral power. It will lead to important changes in the moral structure of society.

313. The steam-engine furnishes abundantly, and on easy terms, that which is required in manufacturing operations,—namely POWER or FORCE. Having rendered this cheap and plenty, it has had the same effect on almost every commodity in the procuring of which *moving power* is required. It has thus rendered cheaper, and brought within the reach of thousands, articles which, in the times of our forefathers, were luxuries enjoyed only by the rich. If we cast our eyes on any one, even the most trifling, of the many conveniences we enjoy (and

which we seldom, perhaps, reflect on, from our familiarity with them), trace it from the raw material furnished by nature, through its various stages of changes by art, we shall find that the steam-engine will meet us at every turn. It is draining the mines ; and, but for it, our supplies of coal would now have been nearly exhausted —or it would have become so dear as to have contracted greatly the sphere of its utility. The steam-engine is at work in our blast-furnaces, forcing in thousands of gallons of air every minute, to extract the tough iron from the brittle ore ; and by the same powerful machine, the cast-iron is formed into bar iron, possessed of strength and tenacity to fit it for suspension bridges, chain-cables, and other purposes, where it has to bear great strains. If the steam-engine did nothing else but thus aid in the procuring of coal, cast-iron, and bar-iron, it would still be one of the greatest gifts presented by genius to man ; but it is hardly necessary to mention that these are but a fraction of the multitude of arts and manufactures which could not now be carried on without the aid of this all-powerful machine.

314. The steam-engine is now beginning to be applied to the diffusion of knowledge, by aiding the printer in his operations. Many of the cheap periodicals, which have no small influence in extending the knowledge, cultivating the understanding, refining the taste, and improving the habits of all classes of society, could not be published at the very low rate charged for them, and which is essential to their efficiency, without the co-operation of the steam-engine. It is thus lending a powerful aid in the advance of improvement—in working out a reformation which, though proceeding by slow and almost imperceptible steps, creeping insensibly, like

Time himself, will advance no less surely, and rival that great innovator in the magnitude of the change it will produce on the whole frame of society.

315. The advantages to our manufactures and trade, in facilitating the transmission of goods and intelligence, cheapening the cost of the interchange of commodities and quickening the rate, bringing distant places near, and rendering the treasures of remote countries more accessible—are obvious enough, and can be easily appreciated. But there are higher considerations than the mere commercial advantages growing out of increased facilities for intercourse between nations. Free intercourse between different countries is eminently calculated to remove those national prejudices, without which war could not flourish. The steam-engine,—when each country is intersected with railroads, and joined to its neighbours by the screw or the paddle,—will be a powerful means of extending friendships, connections, and commercial relations between the people of different lands, and will thus weaken those causes which tend to plunge nations into the horrors of war.

316. PRINTING and the STEAM ENGINE stand side by side as the most powerful material agents ever contrived by man for promoting his advance in civilisation—his progress from the animal to the intellectual. Printing will cause knowledge to penetrate the masses, develope their mental powers, and give them the capacity and the desire for the performance of higher functions than the mere exercise of their brute strength. The steam-engine supplies a substitute for that animal strength; and when its capabilities are fully carried out—as they, doubtless, will be—although it is a difficult social problem, it will do a double service for man. It will do for him that

work, which must be done, which requires mere physical force, while he will engage in the more delicate operation of guiding and regulating the power with which it arms him—and it will lessen his hours of labour, and thereby give him some leisure for the rational recreation, intellectual cultivation, and more refined pursuits, which ought to characterise a being endowed with the superior faculties which have been given to him.

SECTION VI.

HIGH-PRESSURE ENGINES.

317. In the engines which have been described in the last sections, steam, about or near the ordinary pressure of the atmosphere, is used. Such steam is raised at a moderate temperature, and is attended with little risk of an explosion. But it can have no motive power, if resisted by the atmospheric pressure: to give such steam an impelling force, the space into which it acts (pushes the piston) must be a vacuum, or nearly so. Hence the necessity for a condensing apparatus, embracing condenser, air-pump, cold-water-pump, &c. These are termed Condensing or Low-Pressure Engines. They are both costly and cumbrous; and if it is desired to have an engine as cheap, simple, and light as possible, this is effected by dispensing with the condensing apparatus. The steam, in such a case, will be resisted by the atmospheric pressure; and, therefore, to do any work, must have a pressure much higher than steam acting against a vacuum. Simply to balance the

air's pressure, it must have an equal force; and it will exert no impelling power until it exceeds it considerably. Such engines are termed HIGH-PRESSURE, or NON-CONDENSING.

318. Savery's engine was (in the second part of its action) a high-pressure engine. One of the simplest was that invented about 1720, by Leopold, a German, author of the *Theatrum Machinarum.*

Two cylinders with pistons are placed above a boiler, each having an aperture at its lower part, communicating with the boiler, or with the open air, according to the position of a valve, called a four-way cock, interposed between the boiler and cylinders. The cylinders are open above, and the piston rods are attached to levers or beams, which they work. In *Fig.* 22, steam is entering the cylinder *s*, and pushing up the piston, the force of the steam being sufficient to overcome the pressure of the air, the weight and friction of the piston, and the resistance at the other end of the beam. In the cylinder *r* the piston is descending by its own weight, (the steam, which, by the position of the four-way cock, has free access to the air, rushing out,) and thus pulling down the extremity of the beam to which it is attached. When the piston in *s* has reached the top of its cylinder, and that in *r* is at the bottom, the four-way cock is turned so as to admit steam from the boiler into *r*, and the steam in *s* to the air. Thus, steam is again admitted to *r* to push up its piston, and the steam in *s* has access to the air—it rushes out, its elasticity is greatly weakened, and the piston in *s* descends. The four-way cock was contrived by Papin.

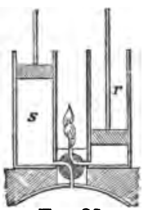

FIG. 22.

This engine was proposed by Leopold for raising water, pump-rods being attached to the extremities of the beams. This was the first high-pressure engine in which the motion was transmitted by a cylinder, piston, and beam; and the steam, after having performed its work, was made to escape into the air — the method now employed in most high-pressure engines.

319. The next high-pressure engine, the first that came into use, was that of Messrs. Trevithick and Vivian, a very simple and beautiful contrivance, and which, while it is applicable to the usual purposes for which condensing engines were used, was the first engine applied to locomotion, in drawing waggons on railways. Their engine was constructed about 1802, and, two years after, was in use upon a railway at Merthyr Tydvil in South Wales.

320. In the engine of Trevithick and Vivian, the boiler was of a peculiar construction. It was of a cylindrical form, with flat ends. The flue carrying off the heated air from the grate, made a bend like a U through the boiler, from one end of it to the other, where it terminated in the chimney. The flame and heated air thus winding through the boiler, communicate a considerable quantity of heat to the water. The cylinder was in a great part immersed in the boiler, by which its temperature and the elasticity of the steam were maintained; and it was closed above, and the *steam* was made to produce the downwards as well as the upwards stroke. The four-way cock was used. It was placed near the top of the cylinder, and communicated with both ends of the cylinders by tubes. By its action, steam was alternately admitted from the boiler to *above* the piston, and from *below* the piston to the air; and

next, from the boiler to *below* the piston, and from *above* the piston to the air. Thus the engine acted with a force proportioned to the excess of the steam pressure above the air's pressure. The steam, upon leaving the cylinder, passed into a tube, which led through a vessel of water, which, being thus heated, was supplied to the boiler by a force-pump. It then entered the chimney, assisted in creating a draught, and escaped into the air. The end of the piston-rod was preserved vertical by slides, as will be described in the next section—on Direct Action Engines. By a fly-wheel the motion was equalised; and, if necessary, it could be regulated by a governor, as already described.

321. As the steam in this engine had a high elastic force, about 70 lbs. to the square inch, and was, therefore, more liable to burst the boiler, besides the usual safety-valve, another was provided, not under the control of the engineer; and in case of the water falling too low, and the boiler thereby becoming too hot, and forming steam too rapidly, or corroding, a small part of the side of the boiler, just below the lowest level at which the water should be, was formed of a fusible metal, as lead, or some metallic composition which melted at that temperature when danger might ensue, and gave exit to the steam. The steam-gauge would also act as a valve, the mercury being expelled by the force of the steam when too high in the limb exposed to the air, and of course too low (or altogether out) of the other.

322. High-pressure engines, being cheap in the first cost, occupying little room, and being easily moved, are now coming much into use. The steam is used of a pressure from about 25 to 80 lbs. on the square inch; sometimes, as in many American engines, from 100 to

150 lbs. pressure on the inch ; but so high a power of steam is not used in this country. It seems not improbable that high pressure steam, applied expansively, and used along with condensation, as in the Cornwall engines, will prove the most economical mode of working steam.

SECTION VII.

DIRECT-ACTION ENGINES.

323. Lately, a class of engines have come much into use, in which the heavy and cumbrous beam is dispensed with, and the piston-rod is applied more or less directly to the crank itself, by which there is a considerable saving in expense, in room, and in weight, of material; all of which are so important in marine engines. Such engines are called Direct Action Engines.

324. Of all *Direct Action Cylinder and Piston Engines*, the most direct, and, perhaps, one of the most successful, is the Vibrating, or Oscillating Engine. In this very elegant contrivance, the piston-rod is attached directly to the crank itself, and plays the part of *connecting rod*. To adapt the rectilineal motion of the piston-rod to the circular motion required in the shaft or axis of the engine, the cylinder, instead of being fixed, is suspended on an axis at its middle part, on which it has motion backwards and forwards, assuming alternately the positions of the two strokes of an X, and vibrating about as much as a beam on its axis. Thus, the piston-rod has a double motion—up and down—and lateral, the latter resembling the motion of the earth's axis from

Precession. The axes on which the cylinder is hung, are hollow; one conveys steam to the cylinder from the boiler; the other is the eduction-pipe, by which the steam passes off. The cylinder hangs upon them in a manner similar to the Eolipile on its axis (*Fig.* 8), but not making a complete revolution, only swinging a little to each side alternately. The action will be understood from the annexed outline of the engines of H. M. steamer, "Black Eagle," which are on this plan, as well as most

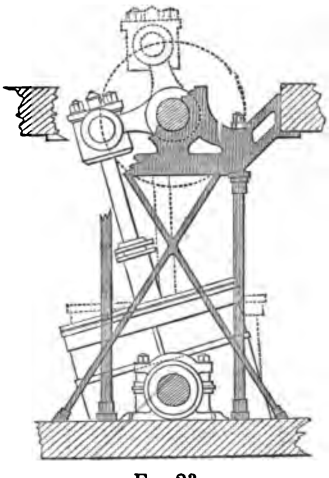

Fig. 23.

of the Thames steam-boats. Mr. Penn, of Greenwich, has been a very successful maker of such engines. They seem to have been first conceived by Messrs. Trevithick and Vivian in 1802, were patented by Witty in 1813, and improved by Maudsley and Field. The piston is represented in the figure with its upper end leaning

towards the left, the piston-rod being at right angles to the crank; the dotted circle represents the circle described by the end of the piston-rod attached to the crank; the other dotted lines show the positions of the parts when the piston comes to the top of the cylinder. JOYCE'S PENDULOUS ENGINES are of a somewhat similar construction, The cylinders are suspended by hollow trunnions at the top, for admitting steam, and are worked on Wolf's principle, of using steam both at high pressure and expansively. They communicate the power direct to the driving shaft without the intervention of connecting gear.

325. Another form of Direct Action Engine is called the Double CROSS-HEAD ENGINE. (See Figures below).

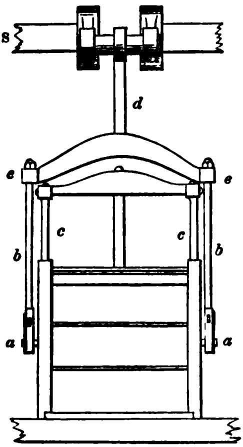

FIG. 24.

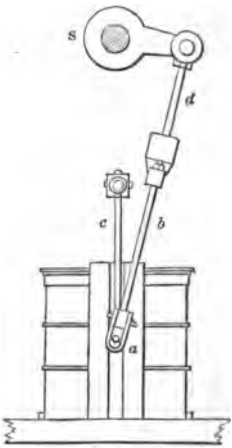

FIG. 25.

At the top of the piston-rod is a bar going across it,

called a CROSS-HEAD. From the ends of this cross-head, *side-rods* (*c c*) hang down by the side of the piston, their lower extremities moving in grooves or slides, by which they (and the piston-rod) are preserved vertical. From the lower ends of these inner side-rods other side-rods proceed upwards, (*a b*) terminating in an upper cross-head (*e e*) to the middle of which is attached a short connecting-rod (*d*), which works the crank. This simple structure will readily be understood from the preceding figures.

326. Another form of Direct Action Engine is often seen in steam-boats ; and, from projecting considerably above the deck, is quaintly termed the *Steeple Engine.* The following figure will illustrate one of the plans by which this is effected.

327. In the adjoining figure, P is the piston, whose rod (*P c*) terminates in a cross-head (*d e*). From the ends (*d*, *e*) of the cross-head, two bent bars proceed upwards, meeting at a point (*o*) in the middle of a short horizontal rod. The piston-rod carries up and down the triangular frame (*o d e*) ; and to the point (*o*) is fixed the connecting rod (*o m*), which hangs down and turns the crank (*m r*) in the usual manner. The extremity of the rod (*o m*) is kept moving vertically, by the ends of the short rod (to the middle of which *o* is fixed) moving in grooves or slides (*b n*), so that the piston-rod,

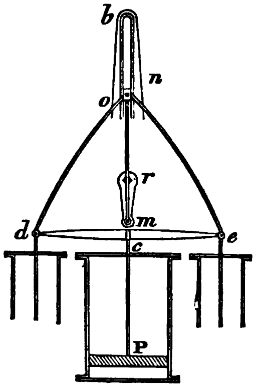

FIG. 26.

notwithstanding the inclined motion of the rod (*o m*), is always preserved perfectly vertical. Thus, through the medium of the triangular frame, the motion of the piston is transmitted almost directly to the rod (*o m*), which turns the crank, while, by the simple contrivance of the slides, the vertical motion of the piston-rod is accommodated to the circular motion of the crank. The crank is double, the cross-head (*d e*) in ascending passing between the two parts of the crank. There are two air-pumps worked by the rods from *d*, *e*, the ends of the cross-head; and two condensers; and the valves and other pumps are worked by eccentric rods attached to the axis.

328. Mr. Wilding, in order to diminish the loss of power in reciprocating steam engines, arising from the direction in which the piston works having to be reversed twice for each turn of the main shaft, has contrived an engine with fewer strokes, by making each stroke of the piston long enough to produce a number of turns of the main shaft. See "Mechanics' Magazine," vol. lii, page 41.

329. Another variety of the Direct Action Engine has been constructed by Messrs. Maudsley and Field, for H. M. steamer "Retribution," and other vessels, with great success. It has a double cylinder, and long connecting-rod descending between the cylinders.

330. Of all these varieties of the Direct Action Engine, the Oscillating and Double Cross-Head seem to be generally preferred. They enable the shaft and piston to be tolerably near each other, so that the engine is compact, give the piston a sufficiently long stroke, and are simple in construction. Length is desirable both in the piston-rod and connecting-rod. There is a smoother

motion the nearer the piston-rod and connecting-rod are to being in one line; and this is the case when the latter is long; while the effect of the steam is better obtained with a certain length of stroke. The Steeple-Engine is in considerable favour, for river, and even for sea-going steamers. There seems some reason to believe that, ere long, the lightness, compactness, and cheapness of the direct action engine, will cause it to supersede entirely the original, or beam-engine, not only on sea, but on land. The finest marine steam-engines in the world, however,—those built by NAPIER, for the Atlantic steamers,—are beam-engines.

SECTION VIII.

ROTATORY ENGINES.

331. IN all the engines hitherto alluded to, applied to produce a rotatory or continued circular motion—as the steam-boat engine, the engine for machinery, whether of direct action or otherwise—the steam produces at first an alternate rectilinear motion, which has to be converted into circular motion, by machinery interposed between the steam and the axis or shaft to be turned. The piston and cylinder, beam, connecting-rod, and crank, are all interposed between the axis and the steam. These are cumbrous and costly; and many attempts have been made to dispense with them all, *by applying the force of steam so as to produce a circular motion at once.* Such an engine, in which the steam is made to act in a circular direction, is

termed a Rotary or Rotatory Engine ; and would be the most *direct* of all in its action.

332. The first idea of such an application of steam seems to have been suggested by Watt in his patent of 1769 ; and from it the mode of construction adopted in a number of proposed rotary engines seems to have been derived. Although not successful, it shows the fertility of Watt's mechanical genius, which had anticipated and thrown out some scheme for almost every variety of form in which steam could be used ; and none upon the plan of direct rotary action has as yet succeeded. The rotary engine is as yet an unsolved problem in practical mechanics.

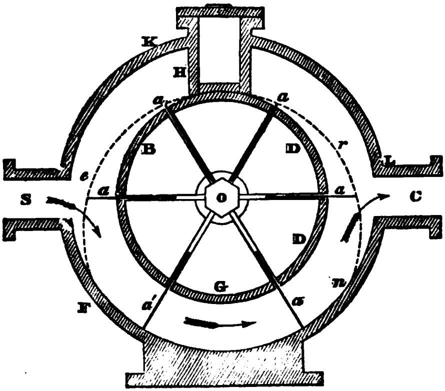

Fig. 27.

333. The above figure is a representation of a rotary engine recently in use, the patent of Mr. Job Ryder, but only a slight modification of one devised by Messrs. Bramah and Dickenson in 1790. A vertical section is shown. F K L and B D G are two cylinders, with a

space between. The shaft (O) to be turned, is fixed to the inner of these cylinders, and revolves along with it. The outer cylinder is fixed. In the inner cylinder are deep grooves or slits, into which the slides or plates *a a* fit, having free motion along the niche or slit. Each slide is connected to the opposite one by pins through the shaft. A fixed partition (H) separates the space between the two cylinders into two divisions. On each side of the partition, there is fixed a *rib*, or part of an eccentric ring, *e a a r n*, shown by the dotted line. The steam is admitted by the opening S, and passes out by the opening C, to the condenser, or to the air, if the engine be a high-pressure one. When steam enters at S, it will press upon the partition H, and the slide *a'*. The partition is immovable; therefore the slide will be pushed in the direction shown by the arrow, and carry round the cylinder B G D along with it, and the shaft O. When the slide arrives at *n*, it will be forced back into its channel by the rib *n r*, and steam will escape by the aperture C. By this time another slide will have come to the position *a'*, and be pushed round in its turn. It will be evident, from the direction of the rib *n r*, that it will gradually push the slides further back into their grooves, till, at the highest point, it permits them to pass the partition H. After they have passed the partition, the rib again permits them to slide out of their grooves, and give effect to the action of the steam upon the cylinder B D G. In this manner the continuous rotatory motion is kept up—*the slides acting as a crank, with the steam applied to it directly.*

334. Most of the rotary engines, as Jones's, Borrie's revolving engine, Lord Dundonald's, have been somewhat similar to this in their general form. Leakage and

friction have hitherto proved insuperable obstacles to the successful working of this class of rotary engines.

335. A rotary engine of a different construction, used in America, has been much talked of. It is exactly on the principle of a Barker's mill, or of Hero's Æolipile, the first machine moved by steam. The principle on which it is constructed will be readily understood by referring to the figure of the Æolipile. An engine of this kind was proposed by Kempel, and described in a German work published in 1794. The arms of the Æolipile, without the ball or globe, and lying horizontally, may convey an idea of this rotary engine. A vertical pipe from a steam-boiler terminated in a horizontal arm, which had free motion round the pipe. The arm was hollow, and had apertures at *the opposite sides* of its two extremities, by which the steam issued and propelled the horizontal pipe in a direction opposite to that in which the steam escaped. This is an extremely simple piece of machinery. Perhaps no engine can be simpler in construction. It has been lately revived by an American, Avery, with some success in his own country; and several have been constructed by Mr. Ruthven, of Edinburgh. The arms are about five feet long, five and a-half inches broad, flattened like the sheath of a sword, and sharpened at both edges, so as to receive as little resistance as possible from the medium in which they move. The apertures by which the steam issues, are 1-4th inch in diameter, 1-20th square inch in area. The engine constructed by Mr. Ruthven, and in operation at his works, is about fifteen horse power. It may be worked with a pressure of from 30 to 70 lbs. per inch on the safety-valve, and, when in full action, the arms make about fifty revolutions in a second. They

are set vertically, and revolve in a cast-iron case, about eight inches wide, so that they are not seen. Such engines are compact, light, and very cheap ; but do not give out the whole power of the steam, and have latterly rather gone out of favour.

336. Another variety of Rotary Engine is that of which the steam-wheel of Branca may be taken as the germ (195-6-7). It has recently been revived in a more efficient form by Mr. Pilbrow, and the principle of its action, it is supposed by some engineers, will yet prove the true basis for the rotary engine. At present, the *momentum*, or moving power of steam, does not appear in a form likely to be available for economical use.

337. For the adaptation of any power for producing motion, it must be considered not only theoretically, but with regard to the means of constructing nicely-fitting machinery capable of giving effect to it, and with respect to the tear and wear of that machinery. Theoretically the rotary engine of the first class mentioned, is the most perfect form in which steam can be employed ; but the two practical difficulties just alluded to, have not yet been overcome ; and the cylinder and piston, with the reciprocating rectilineal motion, remain still the best adapted form of machinery, all things considered, for giving effect to the force of steam for producing every kind of motion and pressure.

SECTION IX.

STEAM NAVIGATION.

338. THE application of the power of steam to navigation, whereby voyages might be made in a dead calm, or even when the wind is adverse, was sufficiently obvious; and, accordingly, we find that every projector of machines for applying steam as a power, contemplated its introduction as a means of impelling vessels along their liquid path. We have already noticed the project of Blasco de Garay in the sixteenth century. Of that nothing further is known, than that such a design was by him put in execution, and then abandoned. Papin projected the application of his engine to navigation, but seems to have gone no further than throwing out the idea that a paddle-wheel attached to a vessel might be turned, and thus give motion to the vessel, by water to be raised by the engine.

339. The first feasible-looking project for a steam-boat was that of JONATHAN HULLS, who took out a patent for it in 1736, and, in 1737, published a description of it, with a drawing, entitled, "A Description and Draught of a new-invented Machine, for carrying Vessels or Ships out or in of any Harbour, Port, or River, against Wind or Tide, or in a Calm." His power was procured by the pressure of the atmosphere against a vacuum, just as in Newcomen's engine; and, by very ingeniously devised machinery, he transmitted the motion to a paddle-wheel at the stern, and provided for the

continued rotation of the wheel during the ascent of the piston. Newcomen's engine, however, was not very well adapted for yielding rotary motion; and Hulls's project was soon neglected and forgotten. Mr. Tredgold remarks, "that it was certainly a beautiful contrivance for rendering so irregular a first mover equable;" and also "the pamphlet of Hulls bears evidence of being the work of an ingenious and well-informed mind."*

340. From the time of Hulls, up to the period of the introduction of Watt's improvements, no attempts to apply steam to navigation have been recorded. It is said that in 1775, a small steam-boat was built in France, by a M. Perier, and tried on the river Seine; but the scheme was abandoned. A larger vessel, to be propelled by the same power, was constructed at Lyons, by the Marquis of Jouffray, in 1782; but his schemes were overturned by the turmoil of the Revolution. The steam-boat he constructed was 140 feet long, 15 feet wide, and is said to have plied on the river Saone, at Lyons, for a considerable time. In 1788, an engine for propelling a boat by the power of steam was built by MR. SYMINGTON, an engineer, under the patronage (some say under the directions) of Mr. Miller, of Dalswinton. Mr. Miller had constructed a double boat, with paddles in the middle to be impelled by manual labour. A Mr. Taylor is said to have suggested steam-power instead. A canal boat, impelled by a steam-engine, built by Mr. Symington, plied with some success on the Forth and Clyde Canal

* The paddle-wheel is an old invention. It was used by DE GARAY. PRINCE RUPERT, about 1680, had a barge moved by this contrivance. SAVERY proposed a paddle-wheel to be driven by manual labour. It was for the purpose of driving the paddle-wheel of a boat belonging to Mr. Millar of Dalswinton, that the experiments were instituted which led to the establishing of steam as a power fit for navigation.

in 1789; but the scheme was abandoned, the agitation of the water by the paddles being found to injure the canal banks; and was not prosecuted elsewhere. In 1790, Fitch and Ramsey, of Philadelphia, are said to have constructed a steam-boat which plied successfully on the Delaware. In 1795, the ingenious Lord Stanhope constructed a machine for propelling vessels, which was tried in London, but did not prove successful. About 1796-9, a steam-tug with paddles was tried on the Duke of Bridgewater's canal, but soon given up. In 1801, Mr. Symington, at the instigation of Lord Dundas, constructed a steam-boat for towing vessels on the Forth and Clyde Canal. The project seems to have been tolerably successful, but was again strangely abandoned. Mr. Symington certainly possesses considerable claims to being regarded as the inventor of steam navigation. He not only constructed efficient steam-vessels, but his plans aided those who followed and were more successful in establishing them. His claims are asserted in a pamphlet, entitled, "A Brief Narrative, proving the right of the late William Symington, civil engineer, of Falkirk, to be considered the Inventor of Steam Land Carriage, Locomotion, and also the Inventor and Introducer of Steam Navigation. By Robert Bowie." In a letter in No. 795 of the "Mechanics' Magazine," Mr. Bowie states, "Mr. Symington fitted and propelled four boats with the steam-engine: the first in 1788, on Dalswinton Lake; the second in 1789, the third in 1801, and the fourth in 1803, on the Forth and Clyde Canal." MR. FULTON, the American engineer, Mr. Bowie states, went a voyage of eight miles in an hour and twenty minutes, in Mr. Symington's third boat, in 1801 or 1802, examined particularly, and took notes of all Symington's arrangements.

In fact, his knowledge on the subject was mainly derived from conversation with Symington, and from examination of the marine engine devised by that engineer.*

341. The first really successful steam-boat was built at New York, and launched in 1807. It was constructed under the superintendence of Mr. Fulton. The engine was built for him by Boulton and Watt, and sent out to America. Fulton had been experimenting in France, and had proposed to Bonaparte to employ steam-vessels in his intended invasion of Great Britain. Receiving little encouragement in Europe, he returned to America, and there completed his plan. The first considerable steam voyage was successfully performed by his vessel, between New York and Albany (a distance of 160 miles, performed in about thirty hours); and this public demonstration of the practicability of steam navigation gave the impulse which has set steam in action on the waters in every quarter of the globe. Fulton's project was a good deal laughed at; and his steam-boat was called "*Fulton's Folly.*" He deserves great credit for his perseverance, notwithstanding the ridicule and apathy he met with. Such was the temper of some of his own friends on the subject, that, after he had even conducted them safely to Albany, in the first trip which his steam-vessel made, he was told *he could not do it again, and, supposing he could, what would be the use of it!* The sensation produced by the appearance of Fulton's vessel making its way over the waters, was thus described in an American paper:—

"She had the most terrific appearance from other vessels which were navigating the river. The first

* See Vols. 19 and 35, Mechanics' Magazine.

steamers, as others yet do, used dry pine wood for fuel, which sent forth a column of ignited vapour, many feet above the flue, and, whenever the fire is stirred, a galaxy of sparks fly off, and, in the night, have a very brilliant and beautiful appearance. Notwithstanding the wind and tide were adverse to its approach, they saw, with astonishment, that it was rapidly coming towards them; and, when it came so near that the noise of the machinery and paddles was heard, the crews, in some instances, shrunk beneath their decks from the terrific sight, and left their vessels to go on shore, while others prostrated themselves, and besought Providence to protect them from the approach of the horrible monster which was marching on the tides, and lighting its path by the fires which it vomited."

342. Fulton thus demonstrated the capability of steam to be applied as a moving power for ships. A few days after his successful steam-trip to Albany, another American, Stevens, who had been long engaged in experiments in steam navigation, effected a successful steam voyage in a boat he had constructed; and, in the course of a few years, steam-boats were to be seen plying on the shores, and along the rivers, in all the populous districts of the United States. As a tribute for his services to society, the American Government have awarded a handsome grant to Fulton's heirs. Is not this country under similar obligations to Symington and Henry Bell?

343. In 1812, a steam-boat, called the Comet, began to ply on the Clyde, between Glasgow and Greenock. It was of three-horse power, and moved at the rate of five miles an hour, against a head wind. This was the first successful steam-boat in Europe, and was the result

of the skill and enterprise of MR. HENRY BELL. A monument has lately been erected to his memory, on the banks of the Clyde.

344. Since that time, steam navigation has made rapid progress. In 1815 and 1817 steam-vessels first ventured out to sea; and in 1818, MR. DAVID NAPIER established a regular steam-boat communication between Greenock and Belfast, by the "Rob Roy" steamer. In 1821, steam-vessels were established between Edinburgh and London, namely, the "James Watt" and "Soho," with engines built by Boulton and Watt. The success of these steamers, on a long and often very rough voyage, established the capability of steam power for any European voyage; and accordingly steam-vessels were soon to be seen of large size and power, plying along all the coasts of Europe. In 1826, the "Enterprise" steamer went from London to Calcutta, calling at the Cape of Good Hope; but not with such success as to give encouragement for very long steam voyages.

345. The next grand step in steam navigation was crossing the Atlantic. The "Savannah," an American steam-vessel, Captain Rogers, commander, had crossed the Atlantic in 1819, leaving Savannah on the 25th May, 1819, and arriving at Liverpool on the 20th of June; but not steaming the whole way. The "Curaçoa," a steamer, with two 50-horse power engines, went from Holland to Surinam in 1828, sailing, however, a great part of the way. I have been informed also, that "the steam-ship, 'Royal William,' Captain John M'Dougall, built at Quebec, left that city under steam on the 12th of August, 1833, called at Pictou, U.S., and arrived in London on the 3rd of September, same year; that she steamed the whole passage, and

stopped four different times, each time thirty hours, to clear and clean the boilers from incrustation and sediment."

346. But, although there may have been several isolated voyages made across the Atlantic, and others as difficult and dangerous, previous to 1837, there can be no doubt that the practicability of regular voyages across the Atlantic Ocean was first established by the success of the "Great Western" steam-ship in 1838, which left Bristol on the 8th of April, and reached New York on the 23rd. This fine vessel was built by Patterson, of Bristol, for a spirited public company of that town, *expressly for Atlantic navigation.* Brunel was the consulting engineer of the company, and the engines were made by Messrs. Maudslay and Field. The success of the "Great Western" * led to the establishing of that very fine line of steam vessels, usually called the "Cunard Line of Steamers," plying between Liverpool on this side, and Halifax, Boston, and New York on the other side of the Atlantic; and ultimately to the still longer voyages undertaken by the West India and South America mail steamers; and there can be little doubt that, ere long, every port on the surface of the globe will be rendered accessible with the speed and certainty which steam alone can ensure.

THE STEAM-BOAT ENGINE.

347. In the marine steam-engine, the power is applied to turn a strong shaft or axis, to which is attached a

* The GREAT WESTERN was preceded in starting by a few days, and in arriving by a few hours, by the SIRIUS, started by the Company which built those leviathan vessels the BRITISH QUEEN and the unfortunate PRESIDENT, for the Atlantic navigation.

paddle-wheel or screw. To the rim of the paddle-wheel are attached a number of flat boards (or paddles) at regular intervals. When the wheel revolves, these *paddle-boards* act upon the water in the same manner as the oars of a boat, the resistance of the water propelling the vessel in a direction opposite to that in which the paddle acts upon the water. The lower paddles are always under the surface, and, by the revolution of the wheel, a continued impulse is given to the vessel. In this country, condensing engines are generally used for steam-vessels. They are on the same general plan as the double-acting engine of Watt, differing slightly in the construction and relative position of the parts.

348. In most steam-vessels two engines are used, acting upon a common axis, and with the cranks so arranged that when the crank of one is at its critical points, that of the other is in full action; and thus the continuity and tolerable uniformity of the motion is insured, without the encumbrance of a fly-wheel. In other steam-boats, only one cylinder is used. The manner in which the parts are arranged in steam-boat engines, will be readily understood from the following figures. *Fig.* 28 is a view looking across the vessel;

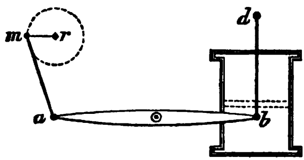

FIG. 28.

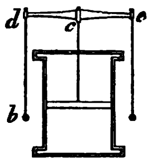

FIG. 29.

Fig. 29 along it. There are TWO BEAMS, one at each side of the cylinder, near the lower part,—not above the

cylinder, as in land engines. The piston-rod has a cross-bar (or cross-head), (*d e*, *Fig.* 29,) attached to its upper extremity, and passing over the cylinder in a transverse direction in relation to the boat. The cross-head *d e* is preserved vertical by slides; or by a parallel motion similar in principle to that already described (See par. 288). From the ends of this cross-head *d e*, side-rods hang down, attached to the ends of the beams at their lower extremities, and playing on pivots at both their connections with the cross-head and the beams. One of these is marked *d b*, in *Fig.* 29, which represents a view of the piston, with its rod, cross-head, and side-rods, as seen looking along the boat. *Fig.* 28 is a side view, showing the piston, one side-rod, one beam, and the situation of the crank, and axis or shaft, marked *r*, which turns the wheels. The beam is in the horizontal position, and the piston, as shown by the dotted line, in the middle of the cylinder.

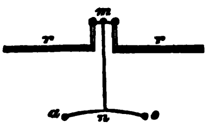

FIG. 30.

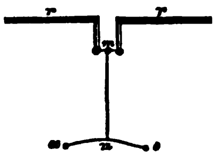

FIG. 31.

349. *Figures* 30 and 31 will illustrate the manner in which the motion is transferred from the beams to the axis (*r*). A cross-bar (*a o*) is attached to the extremities of the beams farthest from the cylinder. To the middle point (*n*) of this cross-bar is fixed the rod (*n m*) which works the crank. The crank is double; two of its extremities being fixed to the axis *r*. The other two

ends of the crank are connected by a short transverse bar (crank pin) to the middle of which (*m*) the rod *n m* is fixed. The paddle-wheels are firmly fixed to the rod *r*, which communicates the motion to them.

350. The action will be readily understood, with the aid of the preceding figures. The piston-rod raises and depresses the cross-head *d e* (*Fig.* 29), with which the side-rods rise and fall; and these elevate and depress the extremities of the beams (*b*) to which they are attached. The other ends of the beams, alternately rising and falling, carry the cross-bar *a o* (*Figs.* 30-1) along with them, which, communicating its motion to the crank by the connecting rod *m n* (*Figs.* 30-1), gives a continued circular motion to the axis, the extremity *m* of *n m*, describing the circle shown by the dotted line in *Fig.* 28. *Figures* 30-1 show different positions of the crank.

351. The engines of the "Great Western," the *American line of Mail Steamers*, and the *West India Mail Steamers*, are upon the above or side-beam plan; but the direct action engine is now beginning to be introduced, even in the largest size of vessels, and there is reason to believe will soon become general in steam-vessels. The Gorgon plan, introduced by Messrs. Seaward; the steeple-engine, invented by Mr. D. Napier; the Siamese-engine of Messrs. Maudslay and Field; the double cross-head, and the oscillating engines, are the forms most usually met with at present. See the section on "Direct Action Engines," for an account of these varieties.

352. In the boilers of land engines, the earthy and saline matters contained in the water, and which are not evaporated along with the pure watery part, are depo-

sited, falling down and forming a crust at the bottom, which requires occasionally to be cleaned out. But the quantity of such sediment is not great. In the case of marine engines, however, it is very different. The sea-water, with which the boiler is supplied, contains a very large proportion of saline matters (about three per cent.), and this, deposited at the bottom, would very soon produce a serious impediment to the action of the engine, as well as cause some danger of explosion. From sea-water there is deposited, not only common salt, but sulphate of lime, which forms an extremely hard crust, difficult to be removed, and giving a slow passage to heat; so that, from the heat not being rapidly withdrawn by the water, the boiler (if the incrustation be thick) may be rendered red-hot. Also, much fuel is wasted.

353. It has been customary hitherto to retard the deposition of solid matter by an operation termed *blowing out.* This consists in allowing hot water to escape frequently from the boiler. The hot water contains, besides the salt it had when it first entered the boiler, the salt of a great quantity of the rest of the water. For, 100 parts of sea-water contain three of salt; but that quantity of water *can hold in solution thirty-six parts of salt;* hence, 100 parts of water run out, will contain the salt of eleven other hundred parts of water, besides its own. Thus the salt will be carried out, and little deposit will take place. Of course, a waste of fuel will attend the removal of water which has been heated, but has not been formed into steam to exercise any moving power. This loss has been estimated by Mr. Tredgold at 1-54th part. This is not a great proportion; but the plan does not entirely prevent deposit. Hence, a number of schemes have been

proposed for remedying this great defect in marine engines.

354. Lieutenant Gordon, R.N., who has had much experience in the management of steam-vessels belonging to the Royal Navy, and who has paid much attention to the subject, states, amongst others, the following as leading points necessary to the fullest development of economy in marine steam-engines: working the steam expansively, cutting it off at *one-tenth* of the stroke; using the steam with a load on the safety-valve of not less than 45 pounds per square inch; the employment of condensers on the cold surface principle, whereby blowing off is rendered unnecessary, and incrustation prevented, supplying the waste of the *feed-water* of boilers from the evaporation of salt water; using boilers of the locomotive description, but without the blast-pipe; and various arrangements for economy of fuel, such as heating the salt water to be evaporated in flat chambers surrounding the funnel, sending the feed-pipes through the smoke-boxes, &c.

355. Hall's Patent Engine.—The leading peculiarity in Hall's engine is the condenser. By its construction, the same water is used over and over again for forming the steam (as in Howard's engine), and water free from earthy matter being employed at first, there is no deposit nor incrustation in the boiler. The vapour is condensed without any injection water. This is managed by forming the condenser of a number of slender tubes, which are placed in a cistern of cold water, and, presenting a large surface to the water, are continually kept at a very low temperature, by which the steam in the interior is quickly and effectually condensed. This project is believed to have originated with Mr. D.

Napier. From the cylinder, the steam passes into a shallow chamber, from the lower part of which the tubes proceed. They are open above and below. The steam enters them, is there condensed, falls out below as water, and is pumped out by an air-pump, and conveyed back to the boiler in the usual manner. The waste from leakage is supplied by distilling sea-water, for which an apparatus is provided. By an ingenious form of the safety-valve, the steam which, in the usual form of marine engines, escapes into the atmosphere when the engine is stopped or works at a slower rate—is conveyed to the condenser, so that from this source there is no loss of the pure water used. The advantages of this engine in saving fuel, preserving the boiler from being destroyed, either by corrosion of the salt, or action of the high temperature caused by incrustation, and several other improvements which it presents, have brought it much into notice. It has been employed both on land and water ; but its cost, weight, incomplete vacuum, and difficulty of keeping it in order, have operated against its general introduction.

356. CRADDOCK'S CONDENSER.—Mr. Craddock, the inventor of several very ingenious modifications of land, marine, and railway engines, has proposed to condense by currents of air passing between tubes containing the steam, as in Hall's condenser—an extremely simple contrivance, if efficacious.

357. In some marine engines very ingenious contrivances have been introduced, called *sediment collectors.* Salt gauges have also been proposed, for ascertaining the quantity of salt in the water in marine boilers. These act on the principle of the hydrometer, the specific gravity of the water increasing as it has more salt in solution. A little is drawn off into a glass for testing by

the salt gauge, thereby affording useful information as to the necessity for blowing off.

358. The paddle-wheel, in its ordinary form, occasions some loss of power at the moment when the floats enter and leave the water, striking the water *upwards* or *downwards*, at these times, in a manner which contributes little towards the forward movement of the vessel; and there have been many contrivances to prevent this waste of power. The object sought is, generally, to cause the floats to enter and leave the water perpendicularly, or nearly so. This has been effected by contrivances for causing the floats to change their positions at certain points; of which MORGAN's wheels have been very much employed. Another description, called the cycloidal wheel, by Field and Galloway, is frequently adopted.

359. It has been thought desirable that the paddle-wheel should be capable of being separated from its connection with the engine, so that the paddles might turn with the motion of the vessel through the water, when the action of the engine is suspended, and the vessel is propelled by sails. The paddle and floats, when fixed, offer a serious resistance to the motion of the vessel, and render it less manageable when the machinery is not in action. Several ingenious contrivances have been devised for this purpose.

360. The swell and surf occasioned by the action of paddle-wheels, which render them unfit for canals—the varying extent to which they are immersed in a rough sea—the impediment which they offer to sailing (the wheels resisted by the water, and the paddle-boxes by the air)—the large space they occupy at the sides—and their being so exposed that they would be very certain

to be destroyed by a few shot, as well as other inconveniences—have rendered it desirable to have means of propelling vessels by steam, that would be free from the above disadvantages. Of the schemes for this purpose, the most interesting is the *screw-propeller*. Many different plans have been offered for propelling vessels by means of the screw. The following figure and description (from the Mechanics' Magazine, No. 830) will convey some idea of the nature of the screw-propeller of Mr. Smith, one of the first who established the screw as

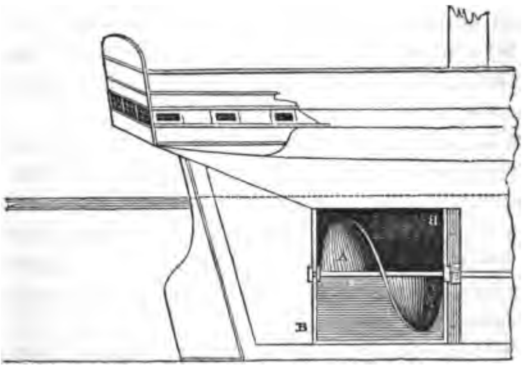

FIG. 32.

an efficient means of propelling vessels. "A A is the blade of the propeller, being one turn of a screw, forming an angle of about 40 degrees with the shaft or axis ; it is made of iron plates, strengthened by wrought-iron arms. B B is the frame fixed in the deadwood of the vessel, to support the propeller. The shaft or axis passes through a stuffing-box in the after part of the frame, and stern of the vessel, and onwards to the engine, by which it is

made to revolve. For every revolution of the crank-shaft of the engine, the screw turns about 5½ times. The screws are made movable, and fixed on to the shaft with keys, so that different sizes may be used under different circumstances. The diameters of the screws which have been used are 5 feet and 7 feet, and their lengths 7½ and 8 feet."

361. Mr. Lowe's propeller consists of a shaft or axis, in a similar situation to that shown in Fig. 32, and having attached to it, instead of a screw, "four curved blades, each a portion of a curve, which, if continued, would produce a *screw*." It is thought by the inventor to have an advantage over the above construction, in permitting the water to pass freely away, while the screw causes a sort of choking action.

362. These contrivances are sometimes called *Archimedean*, from the resemblance they bear to Archimedes' screw. The latter, however, was a hollow tube in a spiral form, and set in an inclined position, the lower extremity being immersed in water, the raising of which, by turning the screw, was the object of this celebrated machine.

363. Another propeller, devised by Captain Ericsson, has been much talked of, and introduced in several vessels belonging to the United States Government. It consists of two screw paddles placed at the stern, and revolving in opposite directions, so as to produce somewhat of the same effect as sculling. It can be made so as to be easily unshipped, or applied to ordinary sailing vessels. The following figure will convey some idea of Ericsson's propeller. There are two shafts—one within the other—the inner of which works the furthest out propeller. A, B are the propellers, *c d* a stay to keep

them firm ; R the rudder, with a hole for the shafts to pass through, and strong iron bars to bind the upper and lower parts firmly together.

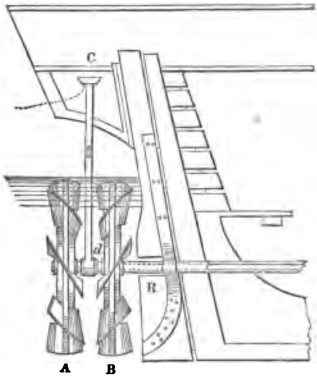

FIG. 33.

364. Instead of a whole convolution of a single-threaded screw, as in Fig. 32, two half-turns of a double-threaded screw placed opposite to each other, are now preferred, or even a much smaller section than a half—the screw then consisting of two plates or blades projecting obliquely from the opposite sides of a shaft. There has been considerable difficulty in adjusting the engine to the screw ; a very high velocity being necessary in the screw, which is destructive or injurious to an engine; or if the engine be made to move moderately, troublesome to procure from that slow motion of the piston, being generally done by cog-wheels. In cases where a great speed is not desired, the piston-rod is applied directly to the crank which turns the shaft of the propeller.

365. One of the most successful steamers upon the screw principle, is H. M. yacht, FAIRY. This vessel has often attained a speed of nearly 16 miles an hour. The screw consists of two blades, which make 250 revolutions in a minute, being five times greater speed than that of the engine. She is worked by two oscillating engines, together 125 horse power, made by Messrs. Penn.

366. The great value of the screw, so far as appears at present, will be for vessels of war, and for other vessels intended to employ steam only occasionally, and to be used chiefly as sailing vessels (see par. 371). It has not given a greater speed than the paddle.

AMERICAN STEAM-BOATS.

367. Some account of the state of steam-navigation in the country where steam was first introduced as a moving power for propelling vessels, may be interesting. The following extracts from a very excellent work on *Engineering in America*, by Mr. Stevenson, will convey some notion of the system on which steam-navigation is conducted in the United States:—

"With the exception of the vessels navigating the lakes, and one or two of those which ply on the eastern coast, there is not a steamer in the country which has either masts or sails, or is commanded by a professional seaman."

There are three classes of boats;—the

EASTERN WATER BOATS,

Characterised by "small draught of water, great speed,

and the use of condensing engines of large dimensions, having a great length of stroke." The steam is used of a much higher pressure than in condensing engines in this country. The voyage on the Hudson river, between New York and Albany, Mr. S. states, is now performed in about ten hours; that is, at the rate of fifteen miles an hour.

THE WESTERN WATER BOATS

have "greater draught, less speed, high-pressure engines of small size, worked by steam of great elasticity."

The two preceding classes of boats ply on the rivers, and the frequent shoals render it necessary that their draught should be small.

THE LAKE BOATS

are like sea-going steamers. Plying on the large lakes at the north of the States, they are exposed to tempests, and heavy swells, and surf on the waters, and require to be of a firmer make, and adapted for sailing.

"By far the greater number of the American steam-boats ply on the smooth surfaces of rivers, sheltered bays, or arms of the sea, exposed neither to waves nor to wind; whereas most of the steam-boats in this country go out to sea, where they encounter as bad weather and as heavy waves as ordinary sailing vessels. The consequence is, that in America a much more slender build, and a more delicate mould give the requisite strength to their vessels, and thus a much greater speed, which essentially depends upon these two qualities, is generally obtained. In America, the position of the machinery and the cabins, which are raised above the deck of the vessels, admits of powerful engines, with an enormous

length of stroke, being employed to propel them ; but this arrangement would be wholly inapplicable to the vessels navigating our coasts, at least to the extent to which it has been carried in America."

The following statements regarding the *Rochester*, a river boat, plying at the average rate of fifteen miles an hour, are interesting.

Rochester.—209 feet length on deck and keel ; 24 feet breadth of beam ; breadth outside of paddles, 47 feet ; depth of hold, 8 feet 6 inches ; average draught of water, 4 feet ; diameter of paddle-wheels, 24 feet ; float-boards, 24 ; length, 10 feet ; dip of float-boards, 2 feet 6 inches. One engine ; cylinder, 43 inches diameter, length of stroke, 10 feet.

"When the 'Rochester' is 'pitched' against another vessel, and at her full speed, the steam is often carried as high as 45lbs. on the square inch of the boiler ; and the piston makes 27 double strokes, or, in other words, moves through a space of 540 feet per minute, or 6·13 miles per hour. In this case the circumference of the paddle-wheels moves at the rate of 23·13 miles per hour. In ordinary circumstances, however, the engine is worked by steam of from 25 to 30 lbs. pressure on the square inch ; and in this case the piston makes about 25 double strokes per minute, moving through a space of 500 feet per minute, or 5·68 miles per hour ; and the circumference of the paddle-wheel moves at the rate of 21·42 miles per hour. The rate at which the pistons of marine engines in this country move seldom exceeds 210 feet per minute. The pistons of locomotive engines generally move at the rate of about 300 feet per minute ; but both of their speeds are very far short of the velocity of the 'Rochester's' piston.

"The diameter of the 'Rochester's' piston is 43 inches, and its area 1452·2 square inches. The pressure of the steam in the boiler is 45 lbs. on the square inch; and the engine works expansively, and cuts off the steam at half-stroke. The half of that pressure, or 22·5 lbs., is assumed as the pressure acting on the square inch of the piston. To this 10 lbs. is added as the pressure of the atmosphere, obtained by the use of the condenser; making the whole effective pressure on every square inch of the piston's area, 32·5 lbs. The length of the stroke is 10 feet, and when going at full speed, the piston makes 27 double strokes, or, in other words, moves through the space of 540 feet every minute. Estimating the power of a horse as equal to that exerted in raising 33,000 lbs. one foot per minute, the power of the engine is obtained by the following expression:—

$$\frac{1452 \cdot 2 \times 32 \cdot 5 \times 540}{33000} = \frac{25486110}{33000} = 772 \cdot 3$$

From this it appears that a force is exerted upon the engine equal to that of 772·2 horses; but one-third of this power is supposed to be expended in working the pumps, and overcoming the friction of the machinery, and a power of 514·8 horses remains as the true force exerted in propelling the vessel.

"If the calculation generally adopted in this country were applied to those engines, and only one-fourth of the power deducted, which appears to be an ample allowance for engines of that construction, the power of the 'Rochester' would be equal to 748 horses.

"In the western water boats, when only one engine is used, which is more generally the case, a large fly-wheel, from 10 to 15 feet in diameter, is fixed on the

paddle-wheel shaft, and serves to regulate the motion of the engine, and enable it to turn its centres. The cylinders are invariably placed horizontally, and the engines are always constructed on the high-pressure principle."

Steam of great elasticity is employed in the "Rufus Putman:" it is 138 lbs. on the square inch, under ordinary circumstances; 150 lbs. occasionally; that is never exceeded except on extraordinary occasions. In the "St. Louis," the pressure is 100 lbs. on the square inch. It is not surprising that explosions are frequent in American steam-vessels.

STEAMERS ON THE MISSISSIPPI.

"The paddle-wheel axle is so constructed, that the portions of it projecting over the hull of the vessel to which the wheels are fixed can be thrown out of gear at pleasure, by means of a clutch at each side of the vessel, which slides on the intermediate part of the axle, and is acted on by a lever. When the vessel is stopped, the paddle-wheels are simply thrown out of gear, and the engine continues to work. The necessary supply of water is then pumped into the boiler during the whole time that the vessel may be at rest.

"The fly-wheel, formerly noticed, is useful in regulating the motion of the engine, which might otherwise be apt to suffer damage from the increase and diminution of the resistance offered to the motion of the pistons by suddenly throwing the paddle-wheels out of gear. The water for the supply of the engine is first pumped into a heater, in which its temperature is raised, and is then injected into the boiler."

Mr. Stevenson considers that the explosions, so frequent and so fatal in America, are caused sometimes simply by the very high pressure—often, by a deficient supply of water, causing the boiler to become red hot; and water being then pumped in, is suddenly evaporated in larger quantities than can escape by the valve—the most common cause in steam-boats in this country.

The boilers rest on the paddle-wheel guards, one on each side of the vessel. The furnace is so placed that the ashes and charcoal fall into the water. The glare from the furnaces forms a very striking feature on the rivers at night. Pine timber, bituminous coal, and blind coal or anthracite, are the sorts of fuel used in the American steamers. The beam is above the cylinder, projecting, indeed, high above the deck, and forming a remarkable feature in the American steamer.

Dr. Lardner states, that within the last ten years changes have been made in the steamers plying on the Hudson river, having a tendency to augment their magnitude and power, to diminish their draft of water, and to increase the play of the expansive principle; that increased length and beam have been resorted to with great success; and that vessels of the largest class now draw only as much water as the smallest drew a few years ago; and that 4 feet 6 inches is now regarded as the maximum. He mentions that the new and largest class of steamers are capable of running from 20 to 22 miles an hour, and make, on an average, 18 miles an hour with little effort; that the steam is universally worked with expansion, being cut off at half-stroke; that the steam is used from 40 to 50 pounds pressure above the atmosphere, and often with condensation; that the fires are urged by fanners, worked by an independent

engine; that the wheels are propelled, generally, by a single engine; that in some boats the wheels are propelled by two engines placed at the platform which overhangs the boat at either side; each wheel being propelled by an independent engine; the wheels acting independently of each other, and without a common shaft or axle, which leaves the entire space in the boat from stem to stern free from machinery, and enables such boats to have magnificent saloons nearly 300 feet long; that the great magnitude and velocity of the paddle-wheels enable them to perform the office of fly-wheels, and to carry the engine through its dead points with little perceptible inequality of motion. The paddle-wheels are from 30 to 40 feet in diameter.

368. The progress of steam navigation has been steady and rapid. In 1814, Great Britain and Ireland had only 11 steam-vessels, in all, of 542 tons burthen. Now there are about 1000 steam-vessels belonging to the United Kingdom, whose tonnage amounts to nearly 150,000 tons burthen. The tonnage of the Cunard line of steamers runs from 1423 to 2266 tons; the horsepower from 500 to 800. The "Comet," of Henry Bell, was a small vessel of only 25 tons burthen, and the engine was only from 3 to 4 horse-power. The "Great Britain" (a screw steamer), which made some successful voyages across the Atlantic before she was disabled in Dundrum Bay, was 322 feet long, and 2500 tons burthen; she had engines of 1000 horse-power, which weighed 340 tons, her boilers weighed 200 tons, and she could stow away 1200 tons of coal. In another respect, the speed attained, the progress of steam navigation has been striking. The "Comet" went at the rate of 5 or 6 miles an hour; light river-boats now make from 15 to

18 miles an hour; while the large heavily-laden, sea-going steamers go from 12 to 14 miles an hour in calm weather, and even from 8 to 10 miles an hour against a head wind. At first, the steam-boat showed itself only on the rivers, or crept timidly along the coasts, like the child clinging to chairs and tables when first it tries to walk alone. Now it braves the roughest seas, and boldly ventures to cross the large oceans and trust itself alone on the deep, thousands of miles from land.

369. The distance from Liverpool to New York is about 3500 miles. The steam-packets make the voyage in about $12\frac{1}{2}$ days, being at the rate of $11\frac{2}{3}$ miles an hour. But the "Pacific," on one occasion, made the voyage from Liverpool to New York in 10 days 5 hours; and the "Asia" once made the return voyage in 10 days 12 hours, being nearly 14 miles an hour. The average time of the sailing packets for both voyages is 52 days; so that the steam-ships cross the Atlantic twice in about half the average time required by the packets. The average voyage from Liverpool to New York is 32 days; from New York to Liverpool, 20 days. The results that may be expected to follow these great demonstrations of the capability of steam for long voyages can hardly be too highly estimated. The superior safety and regularity of steam-vessels—independent of their greater speed—have been fully shown by the steamers between London and Edinburgh, which have now been plying for nearly thirty years, and by those between London and Aberdeen, England and the Mediterranean; and now that nearly fourteen years trial have shown the speed and safety of steam communication between England and the United States, and that steamers have been plying for ten years between England and the West

Indies, it may be said to be proved to be applicable for the whole world. India, by the Cape of Good Hope, Australia and the Pacific (by the canal across the American isthmus), China, Japan, and the Indian Archipelago, will soon be brought nearer Europe by the same powerful agent; and thus greatly increased facilities will be given for friendly intercourse, commerce, and the mutual exchange of the benefits of knowledge and civilisation *between all the nations of the earth.*

370. It cannot be expected, so far as we see at present, that a very much higher speed will be attained than that now reached—namely, for river vessels, 15 to 18 miles an hour; for large sea-going vessels, from 13 to 14 miles an hour in smooth water, and 8 or 9 against a head wind. The resistance of the water increases rapidly as the velocity increases (being as the square of the speed), and the power required is as the cube of the velocity; so that high speeds (unless the draft of water can be greatly diminished) require a great expenditure of fuel, and therefore a great increase of velocity is not to be expected in vessels that undertake long voyages, are heavily laden, and require to store up great masses of fuel. There is reason to believe, however, that the velocity may be, in some degree, still further increased by the diminution of the weight of the engine, caused by the substitution of the direct-acting for the side-beam engine—by the substitution of wrought for cast-iron, in the frame, &c.—by saving of fuel, effected by working the steam expansively, and by introducing the tubular form of boiler—and by improvements in the form of the vessel, according to the principles developed by the experiments of the British Association.

371. Steam is now applied to navigation in another

way. Vessels on long voyages often lie a long time becalmed, and in certain latitudes, a vessel has sometimes a chance of finding a favourable wind, if she can get into it, a little distance being sufficient to bring her from a dead calm or an adverse wind into a favourable breeze. From want of means to sail that short distance, vessels often lie becalmed for many days, or even weeks. A small steam-power would effect this, and could be applied so as not to interfere materially with the construction best adapted for a sailing-vessel. The screw is much used with this view. In a work lately published, Mr. Henry Wise states that, on an average, in a passage from England to Bombay, there are—

Hours.	
868	calm, or light airs.
1518	fair wind.
306	foul wind.
2692	

A small engine, propelling the vessel only three miles an hour, would thus quicken the voyage by 2604 miles, reckoning only the saving by steaming during the calm.

SECTION X.

THE RAILROAD ENGINE.

372. In an engine which is to be transferred from place to place, it is evident that lightness and compactness are principal objects. Hence, the condensing engine, with its condenser and air-pump, and the ponderous beam, however well adapted for a stationar

engine, are totally inapplicable for the purpose of locomotion; and the LOCOMOTIVE Engine is always a HIGH-PRESSURE, NON-CONDENSING ENGINE, generally DIRECT ACTION.

373. The first locomotive engine on a railway was that of TREVITHICK and VIVIAN, in 1804. Their engine for this purpose was on the same general principle as that described in Par. 319. The cylinder was horizontal, the piston moving parallel to the road, and turning cranks, by which the motion was transferred to the wheels. This locomotive engine seems to have been very successful; * yet, for upwards of twenty years after, little was done to extend the use of steam as a locomotive power on land. In 1825, carriages for goods and passengers were run on the Stockton and Darlington Railway; but, until the opening of the Manchester and Liverpool Railway in 1830, it could not be said that the public were at all aware of the practicability and advantages of locomotive steam-engines on railways.

374. At first, it was proposed to draw waggons on railways, by ropes attached to stationary engines at convenient distances. This plan was considered necessary from the idea entertained, that if the power were in the carriage to be moved, the wheels would slip on the rail, and be turned round and round, while the carriage would remain still. This is termed *skidding* of the wheels. This would no doubt take place, if the surfaces of the wheel and rail were perfectly smooth, and there were no friction between them. It was supposed that

* The Railway is not a recent invention; lines of rails, of wood, or iron, have long been in use around the coal-pits in Northumberland and other parts of Great Britain.

there was not enough of friction to give a resistance sufficient to cause the wheel to move onwards, instead of turning on its axis. It was also proposed to make the wheel and rail toothed, which was tried ; but the motion was found so rough, and the tear and wear so great, that it was abandoned. Next, to the engine propellers were attached, which took hold of a fixed point, and thus gave a resistance by which the carriage was impelled onwards. But all these schemes were given up when it was ascertained that there really is sufficient friction or resistance between the rail and wheel to prevent any *skidding* of the latter.

375. The locomotive engine is made of wrought iron, and very strong. Its length is about fifteen feet, breadth seven ; and it rests on springs, which are supported by the wheels. On the top of the chimney is a wire-net capping, which arrests the ignited bits of coke, carried upwards by the rapid draught. The outer casing of the boiler is made of wrought iron, and it is a long, somewhat cylindrical vessel, with a number of tubes of thin sheet copper or brass within it, traversing the lower half. It has two safety-valves (Y Y, fig. 35) ; the first is under the control of the engineer, and he can load it to any extent up to a certain limit, and thus regulate the power of the engine. The other is not under his control, and is always loaded so that it does not permit the steam to acquire strength beyond a certain point, a little beyond what is required to work the engine. The tubes which convey the steam from the boiler to the cylinder (S S) are provided with throttle-valves, under the control of the engineer ; so that he can, as necessary, shut altogether or contract the connection between the cylinder and boiler, so as to stop

the engine, or adjust the quantity of steam admitted, and thus produce any desired rate of motion. In these engines, the engineers perform the part of the governor in engines for impelling machinery. There are gauge-cocks, by which the height of water in the boiler may be learned in the usual manner.

376. The steam from the boilers enters the valve box, from which it is admitted alternately above and below the piston. From the cylinder the steam passes by the pipe P to the chimney, after it has produced its action on the piston, rushing there with great force, and producing a powerful draught through the furnace.

377. The top of the piston-rod moves in slides, and has attached to it the connecting rod O, which, by the usual crank, turns the wheel like a common spinning-wheel. The cranks on each wheel are at right-angles to each other, so that they are not both at the dead points at the same time. There is a force-pump by which the boiler is supplied, from the water contained in a carriage called a tender, behind the engine.

378. In many locomotive engines now constructed, the cylinders are not exposed to the air, by which a considerable saving of heat is effected. They are placed in a casing immediately under the chimney, which is kept warm, both by its being near to the end of the boiler, and by the heated air rushing to the chimney.

379. The following figures (34 and 35) will convey a better idea of the usual construction of the boilers of locomotive engines. The circle *b* represents a section of the boiler, which is cylindrical, about six feet long, and flat at both ends. The chimney ascends from the front end. At the other extremity there is a square box, *a e*, behind and below the level of the cylinder, composed

of two castings, one within the other, with a space of about three inches between them. This box is about three feet in length. The inner box is the fire-box, containing the fuel, resting upon the grating. The space between the two boxes is filled with water, and communicates with the lower part of the boiler by the tube *e*, with the upper part by the tube *c*, through which the steam passes. The tubes represented at the lower part of the boiler, pass along its whole length, communicating with the fire-box at one end, the chimney at the other ; the hot air from the furnace passing through them, and producing a considerable heating effect upon the water which surrounds them.

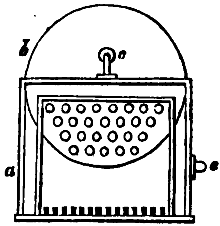

FIG. 34.

380. The following figure will convey some idea of the interior of a locomotive—an example being selected

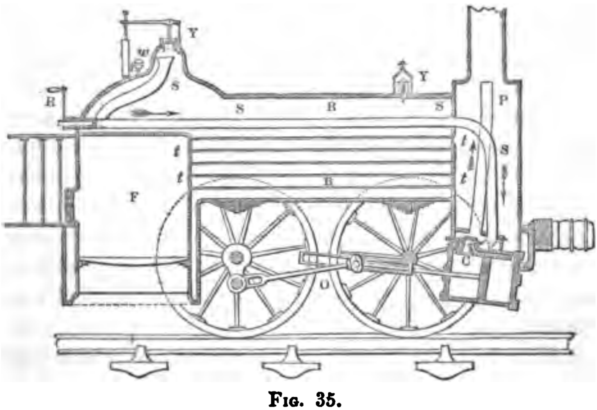

FIG. 35.

for illustration from those running on the London and Birmingham Railway.

381. F is the fire-box, in which coke is consumed, surrounded by water on most sides. The hot air passes from the fire-box along the tubes *t t*, to the chimney. There are usually about ninety of these tubes. B is the boiler. The steam, rising from the surface of the water, passes to the upper part of the dome, and there, having deposited almost all the water mixed with it, it enters the steam pipe, S, and goes to the cylinder, C, from which, after it has done its work, it rushes into the chimney by the pipe P, and aids in making an efficient draught there. O is the connecting rod, having the crank attached to it at one end, while the other moves in slides, to make its motion harmonise with that of the piston-rod. Y Y are the safety-valves; *w*, the steam-whistle; R, the regulator, by which the quantity of steam admitted to the cylinder is regulated. The valves usually employed now are *slide valves*, similar in action to those used in the fixed condensing engine.

382. The Locomotive Engine is one of the most wonderful creations of art. The vast power it wields, concentrated in so small a space; the extraordinary speed it attains; its wonderful capacity for the most rapid changes in its movements—backwards and forwards in an instant, and at any rate within its extreme limits; the variety, yet simplicity, of its parts; their delicate adjustments to each other, combined with their great strength, place it side by side with the watch or chronometer, as one of the grandest triumphs of mechanism.

383. The speed attained on railways has been very great. The rate of fifty miles an hour, even with a

considerable load, has often been effected ; and without a load, engines have on some occasions gone with the uncommon velocity of upwards of sixty miles an hour. An engine in good working condition, with five feet diameter wheels, will draw a load (reckoning its own weight, tender with water, &c.) of fifty tons at the average rate of thirty miles an hour. With rather frequent stoppages, as on most railway lines at present open, the average rate of an engine so loaded may be somewhat less—about 28 miles an hour.

384. Each stroke of the piston (a stroke meaning one motion up and one down) will cause one revolution of the driving wheel ; so that if it be 5 feet in diameter, the carriage will be impelled a distance of 15·7 feet (the circumference of the wheel, a little less than 15¾ feet) for every stroke. Thirty miles an hour is at the rate of half a mile (2652 feet) every minute, for which distance about 168 or 169 strokes of the piston will be required. This is a very high velocity in the piston, and the vibration and concussion produced in the whole machinery by such frequent alternations of the motion—such rapidly reciprocating motions—are not only found to be highly injurious, but form a serious obstacle to any considerable increase in the rate of speed on railways.

385. One method of attaining a higher speed for the carriage, without increasing the speed of the piston, is to enlarge the diameter of the impelling wheels which the piston-rod turns round. By this, one stroke of the piston still causing one revolution of the wheel, while its circumference is larger, it moves over a greater distance ; and thereby a higher velocity is attained, without the piston making more rapid strokes. Of course, the power of the steam must be greater to impel the same load at

a faster rate; but, in proportion as the piston moves slower, there is less tear and wear of the engine.

386. The introduction of large driving wheels renders it necessary that there should be six instead of four wheels to support the carriage. The carriage is kept from going off the rails by the *flange* or projection on the inner side of the tires of the wheels. As a large wheel passes more easily over any obstacle than a small one; so the carriage would more easily go off the rail (a common cause of railway accidents) in proportion as the wheels are large. Where there are only four wheels, it is evident that the flanges of both the front and back pair are necessary to keep the carriage on the rail, so that neither can be made very large. If, however, there be three pair of wheels, the front and back pair will be sufficient to prevent the carriage from going off the rails, and they may be made small, by which they will be very effective for this end; while the middle pair may be very large, and not trusted to at all for keeping to the rails. This has other advantages:—the driving wheel was the most apt to go off the rail; but where there are three, the wheels which retain the carriage on the rails, are not subjected to the direct action of the piston-rod, and are therefore less likely to be driven off. Also, if the axle or any part of the driving wheel be broken, and it is the most liable to this accident, the engine will still be fully supported by the four small wheels.

387. But, even with large driving wheels, the motions of the piston must be very rapid to give a high speed—so rapid as to impair the machinery materially, and not yield the most effective power. This has been regarded by Mr. Watt and others as best attained when the motion of the piston is about 240 feet in a minute;

whereas, even with wheels of eight feet diameter, a velocity in the piston of 420 feet (18 inch stroke) would be required to give a rate of about 40 miles an hour. To remove this great difficulty, it has been proposed to convey the power from the piston to the wheels by tooth-and-pinion gear; which would enable a moderate velocity in the piston to give a high velocity to the wheel.

388. The following extract from the elaborate work of the Artisan Club on the Steam-engine, exhibits a succinct view of several interesting points relating to railways:—

"The tractive force requisite for drawing carriages over well-formed and level common roads, is about $\frac{1}{36}$ of the load, at low speeds. On railways, the tractive force has generally been rated at about $\frac{1}{300}$ of the load, or $7\frac{1}{2}$ lbs. per ton, at low speeds; but in well-formed railways the tractive force is probably less than this, to keep the train moving slowly. The resistance of railway trains, however, increases rapidly with the speed, on account of the resistance of the atmosphere; and the resistance occasioned by the atmosphere may be taken at 15 lbs. per ton, with an ordinary passenger train, moving at the rate of 30 miles an hour.

"The friction of the engine and the resistance of the rails vary simply as the velocity, if the power of the engine remains the same; but the resistance of the atmosphere varies as the square of the velocity, and the power requisite for overcoming that resistance as the cube of the velocity; so that by doubling the speed of a train, by diminishing the load without increasing the power, the friction is doubled, the atmospheric resistance is made four times greater than before, and the power requisite to overcome that resistance eight times greater. This shows the extravagance of high speeds, even if the power were as economically produced at high speeds, which is by no means the case. In moderately light trains, upwards of 50 per cent. of the power is expended in overcoming atmospheric resistance, in speeds of about 35 miles per hour; and the loss will be greater if the trains be very light, and present a large frontage.

"In low-pressure condensing engines the evaporation of one cubic foot of water from the boiler may be taken to represent a horse power. In high-pressure engines, working without expansion, the mechanical efficacy of a cubic foot of water raised into steam will be somewhat less, on account of the resistance to the motion of the piston, occasioned by the pressure of the atmosphere; but in locomotive engines, where the working pressure is very high, the resistance due to the pressure of

the atmosphere becomes, relatively, nearly as small as the resistance due to the rare vapour within the condenser of a condensing engine; and it will not, therefore, be a material deviation from the truth if, in locomotive engines, working without priming, we reckon a cubic foot of water evaporated per hour as equivalent to a horse power. An engine evaporating 200 cubic feet of water per hour, and therefore exerting about 200 horses' power, draws about 110 tons, at 30 miles an hour; but if there were no loss from the resistance of the atmosphere, or of the blast-pipe, and no increased friction upon the engine from the increased power requisite for high speeds, the tractive force, if taken at 8 lbs. per ton, would only require to be 70·4 horses' power, for $110 \times 8 \times 2640$, the number of feet travelled per minute at 30 miles an hour, $\div 33{,}000 = 70{\cdot}4$ horses' power. The friction of the train, however, at 30 miles an hour, including that of an engine of 200 horses' power, cannot be taken at much less than 10 lbs. per ton; for the friction of an engine increases with the power exerted; which determines the pressure upon its moving parts; and the friction of the carriages is also increased at high speeds, in consequence of the draw-bars being attached below the centre of effort of the frontage exposed to the wind; whereby the carriages are pressed down more firmly on the rails. If the traction be taken at 10 lbs. per ton, then the power requisite for propulsion of a train, setting aside the resistance of the atmosphere, will be about 90 horses' power, and the remaining 110 horses' power is absorbed in overcoming the resistance of the atmosphere and of the blast-pipe. If the speed be increased from 30 to 60 miles an hour, about 200 horses' power will be required for overcoming the friction of the train, and 880 horses' power will be required to overcome the atmospheric resistance; making 1080 horses' power, which will be necessary to propel a train of 110 tons at 60 miles an hour. The evaporation of a locomotive boiler is greatest when the speed is at its maximum, as the blast-pipe then produces its greatest effect; and the power of the engine varies nearly as the rate of evaporation, provided the blast-pipe be not unduly contracted. At ordinary railway speeds, the power of the boiler is seven or eight times greater than it would be without the blast; though, indeed, such a comparison hardly holds, as without the blast the fire of a locomotive boiler would not draw at all. At a speed of 20 miles an hour, a locomotive boiler boils off from 10 lbs. to 14 lbs. of water per square foot of heating surface, and the rate of evaporation varies nearly as the $\sqrt[4]{\ }$ of the speed.

"The adhesion of the wheels upon the rails is about one-fifth of the weight when the rails are clean, and either perfectly wet or perfectly dry; but when the rails are half-wet or greasy, the adhesion is not more than one-tenth or one-twelfth of the weight. The weight of locomotive engines varies from 15 to 20 tons. A powerful locomotive engine and tender, such as is suitable for high speeds, will weigh about 25 tons. The consumption of power by the locomotive itself is very great at high speeds, chiefly in consequence of the resistance occasioned by the blast-pipe to the free escape of the steam. Mr. Stephenson con-

siders that, at ordinary railway speeds, a locomotive engine will absorb as much power as 15 loaded carriages, weighing 60 tons; so that, in a train of 15 carriages, half the power is consumed by the engine. These determinations, however, are all very indefinite, and experiments are yet wanting to show the power produced and consumed by locomotives under different circumstances. Locomotive engines cost from 1800*l.* to 2200*l.* each. They run, on an average, about 130 miles a day, at a cost for repairs of about $2\frac{1}{2}d.$ per mile; and the cost of locomotive power, including repairs, wages, oil, tallow, and coke, may be taken at 6*d.* per mile, on economically-managed railways. This does not include a sinking fund for the renewal of engines which may be worn out, and which may be taken at 10 per cent. on the original cost of the locomotives. On second-class railways, the expense of locomotives, and workshops, and tools for repairing them, may be set down at 2000*l.* per mile."

ATMOSPHERIC RAILWAY.

389. A new method of propelling carriages along a railway has been lately tried, called the ATMOSPHERIC. It has excited great interest, and, although it has not hitherto been successful, hopes are still entertained by its supporters that it may yet be established as the best mode of railway propulsion.

390. By the plan of the atmospheric railway, the locomotive engine is dispensed with, and the power to impel the carriage is derived from the air's pressure. The carriage is attached below to a piston fitting in a tube about a foot in diameter, running between the rails along the line. From one end of this tube the air is withdrawn by air-pumps, worked by fixed engines at various intervals; and this gives effect to the air's pressure acting on the other side of the piston, which is thus driven towards the vacuum end of the tube, carrying the carriage, or train of carriages, along with it.

391. It will at once be asked, how can the tube in which the vacuum must be made, be preserved air-tight, an essential condition for procuring a vacuum, and at the same time permit the plater or bar (called coulter) which

connects the piston to the train to pass freely through and along its upper part? This has been one of the grand difficulties of the atmospheric railway—overcome, no doubt, so far as regards the mere practicability of it—but a formidable impediment in the matters of trouble, economy, &c.

392. The slit in the tube through which the air passes, is covered with a moveable continuous valve, which is raised by the coulter as it passes along, and then falls and closes the aperture, being pressed so as to fit tightly to the slit by various ingenious contrivances. The following figure shows the valve of Mr. Mallet:—

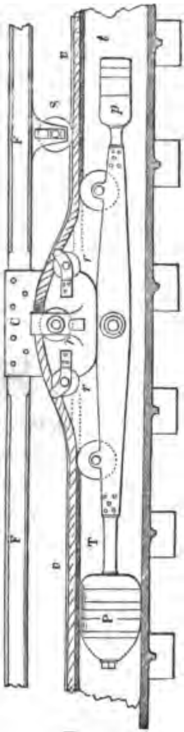

Fig. 36.

P *p* is the piston, T *t* the tube, C the coulter, *r r r* the rollers which raise the valve as they pass along, *v v v* the valve, and F the carriage frame, S a roller attached to the carriage for pressing the valve into its place after the piston has passed.

393. The valve "consists of a continuous hollow tube or hose of woven hemp, coated throughout with *caoutchouc*"—"it is maintained full of water, or brine, in cold climates," and acts like a continuous cork. The rollers (*r r r*) lift up the valve a few inches as the piston travels along, and when it has passed, a roller (S) attached to the back part of the carriage presses the valve back into its seat, and effectually closes the aperture.

394. Another variety of valve is a slit covered by a longitudinal flap of leather, which is fastened air-tight at one side, but loose at the other edge, which is pushed up and aside by the coulter as it passes, and then pressed down by a wheel which follows. To keep it air-tight, this loose edge is made to fall upon a sort of trough or groove filled with a composition of tallow and bees' wax, which is softened by a copper heater, which is connected to the carriage, and melts the composition, so as to keep the valve air-tight as it passes along.

395. The construction of the valve of the atmospheric railway has elicited a vast amount of mechanical ingenuity, and contrivances have even been proposed by which a valve would be altogether dispensed with. MR. PILBROW devised a connection of this description between the piston and carriage, in which it is endeavoured to prevent the waste and remove the difficulties of the valve system. The piston has a horizontal toothed wheel attached to it, which turns a similar wheel at the side of the tube in an air-tight box. The shaft of this latter wheel is upright, or vertical, and passing upwards air-tight through a stuffing-box, gives motion to a similar wheel, which acts upon a corresponding wheel in the carriage, and thus impels it along the line.

396. It has also been proposed to procure the vacuum in the tube of the atmospheric railway by the condensation of steam, instead of by air-pumps requiring powerful engines to work them. Schemes of this description have been proposed by Messrs. Carson, Nasmyth, and Mallet. By this method, instead of a stationary engine, a steam-boiler with a large condenser, in which a constant vacuum is kept up, would be employed—the vacuum in the tube being procured by connecting it with the

condenser—on the same principle as that by which the vacuum is procured in the condenser of Watt's engine.

397. It is considered that the atmospheric system of railway is not well adapted for long lines of railway, nor even for short lines, where the traffic from intermediate stations between the termini has to be looked to; but that, to use the words of Mr. Stephenson's report, "on short lines of railway—say four or five miles in length—in the vicinity of large towns, where frequent and rapid communication is required between *the termini alone*, the atmospheric system might be advantageously applied."

398. On the South Devon Railway, where the atmospheric system was tried for some time, it was at last given up by the Directors, and ordinary locomotives substituted. There seems to be much difference of opinion as to the causes of the withdrawal of the atmospheric system on this line.

LOCOMOTIVE ENGINES FOR COMMON ROADS.

399. In 1831, a steam carriage plied between Gloucester and Cheltenham regularly for four months, on the common turnpike-road. This carriage was constructed by MR. GOLDSWORTHY GURNEY, whose invention it was. Dr. Robinson, Mr. Watt, Oliver Evans, in America, and Mr. Symington, of Falkirk, had projected the idea of using steam for carriages on common roads. Also, previously to Mr. Gurney, attempts to construct a steam-carriage for common roads had been made by Mr. Trevithick in 1802, Mr. Griffiths in 1821, Mr. Gordon in 1824, Messrs. J. and S. Seaward, Messrs. Hill and Burstall, and Mr. Hancock. The first sufficient trial of

steam-propelled carriages on common roads was by Mr. Gurney, who, in 1829, travelled from London to Bath, and back, in his steam-carriage. But, when Mr. Gurney's carriage was running in 1831, the difficulties encountered were so great, from heavy tolls imposed, and obstructions placed on the road, that, after running successfully for four months, it was abandoned. Mr. Gurney petitioned Parliament, and a committee was appointed to report upon the subject.

400. The following extracts from their report contain some interesting information on the subject:—

"Mr. Gurney states, 'that he has kept up steadily the rate of twelve miles an hour; that the extreme rate at which he has run is between twenty and thirty miles an hour.'

"Mr. Hancock 'reckons that, with his carriage, he could keep up a speed of ten miles an hour, without injury to the machine.'

"Mr. Ogle states, 'that his experimental carriage went from London to Southampton, in some places at a velocity of from thirty-two to thirty-five miles an hour. That they have ascended a hill, rising one in six, at sixteen and a half miles per hour; and four miles of the London road, at the rate of twenty-four and a half miles per hour, loaded with people.'

"Mr. James Stone states, 'that thirty-six persons have been carried in one steam-carriage. That the engine drew five times its own weight, nearly at the rate of from five to six miles an hour, partly up an inclination.'

"The committee stated in conclusion:—'Sufficient evidence has been adduced to convince your committee—

"'1. That carriages can be propelled by steam on

common roads at an average rate of ten miles per hour.

"'2. That at this rate they have conveyed upwards of fourteen passengers.

"'3. That their weight, including engines, fuel, water, and attendants, may be under three tons.

"'4. That they can ascend and descend hills of considerable inclination, with facility and safety.

"'5. That they are perfectly safe for passengers.

"'6. That they are not (or need not be, if properly constructed) nuisances to the public.

"'7. That they will become a speedier and cheaper mode of conveyance than carriages drawn by horses.

"'8. That, as they admit of greater breadth of tire than other carriages, and as the roads are not acted on so injuriously as by the feet of horses in common draught, such carriages will cause less wear of roads than coaches drawn by horses.'"

401. Still, steam-carriages have not been established anywhere on common roads, and the attempt seems to have been given up. The destruction of the machinery caused by the roughness of the road seems an insuperable obstacle. No system of springs has yet been devised which will at once neutralise the effects of the roughness of the road, so as to save the machinery, and permit a sufficiently rigid connection between the piston and axle, so as to preserve them in harmonious action. It seems probable that a very great change in the construction of common roads, so as to have them much more smooth and level, must precede the profitable introduction of steam-carriages to run upon them.

THE STEAM-PLOUGH.

402. Among the many purposes for which animal power is employed, *ploughing* is one to which steam machinery has not yet been successfully adapted; although many attempts have been made to construct an efficient *steam-plough*. The same difficulties which oppose the use of steam-carriages on common roads, are still more serious impediments to steam-ploughing. Messrs. Galloway and Purkis have taken out patents for improvements in apparatus for ploughing. The ploughing part of their machine consists mainly of an endless chain, supported and driven by two sets of chain wheels, and having the ploughs fastened to it. These are arranged somewhat on the plan of the dredging machines, used in cleaning docks and deepening rivers. They employ a pair of oscillating steam-engines. The frame-work of their steam-plough is eighteen feet long, and it can cut a double row of furrows twenty feet long to any required depth within the range of the machine, which is twenty inches. To plough fresh furrows, the machine is made to advance progressively at right angles, away from the furrows already cut.

THE BOILER.

403. The boiler is a large vessel formed of sheet-iron plates hammered together, so as to be water-tight. It is made in many different forms; but these are chiefly of two leading kinds, the wagon-shaped boiler, shown in *Fig*. 37; and the cylindrical boiler, represented in *Fig*. 38.

The boiler has two principal tubes, one of which conveys to it water (usually water partly heated by

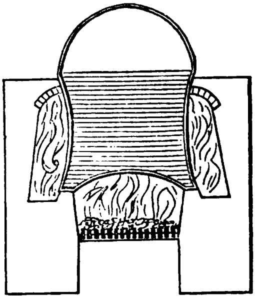

FIG. 37.

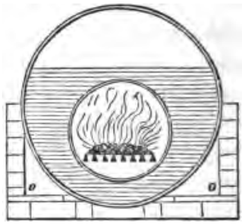

FIG. 38.

being used in condensation) to be turned into steam, while another takes steam from the boiler to the cylinder. The fire is placed below the boiler, as in *Fig.* 37, or in the interior of it, as in *Fig.* 38 ; and the flame and heated air, after coming from the fire, pass along a flue at one side of the boiler, imparting heat to the water, and then along a flue at the other side—which is called the *wheel-draft ;* or, the draft divides on passing from under the boiler into two branches, one to each side flue, which is called the *split draft.* The boiler has *gauge-cocks,* to ascertain the height of the water in it ; a *steam-gauge,* to indicate the elastic force of the steam ; one *safety-valve* (or two), to give timely exit to the steam when it is becoming too strong, and prevent explosion ; an *internal safety valve ;* and a *man-hole,* for admission to clean it. By very ingenious contrivances, the *feed pipe* is made self-regulating, so as to proportion properly the supply of the water to the demand for it within the boiler.

404. GAUGE-COCKS.—The gauge-cocks used to ascertain the height of water in the boiler are the same as in Newcomen's engine, and have been already described. Three are often employed. Another method of ascertaining the height of the water in the boiler will be understood from the annexed figure. There are two apertures in the side or end of the boiler, one near the top, and another near the bottom. These are connected by a glass tube placed outside the boiler, *a b*, in which, communicating freely with the steam above and the water below, the level of the liquid will always be the same as that of the body of water in the boiler; and thus the height of the latter may be ascertained in a moment by a glance at the glass tube. It is now understood that in marine and locomotive engines, these methods, particularly the former, require, at times, great caution in trusting to their indications.

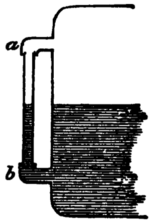

FIG. 39.

405. STEAM-GAUGE.—This is fixed into the boiler, or some tube freely communicating with it, and is open at both ends,—to the interior of the boiler at one end—to the atmosphere at the other. It is curved, in the form of the letter U, and contains a quantity of mercury. The atmospheric pressure acts on the mercury in the limb open to it, with a force of 14·7 pounds per square inch. If the steam act with the same force, the mercury will be at the same level in both limbs. If the steam be of higher elastic power than the air's pressure, it will depress the mercury in the limb on which it acts, and force it up to a corresponding height in the limb open to the air. The difference will indicate the excess

of the force of the steam over the air's pressure. The tube may be of glass or iron. In the latter case, a float with a long rod rests upon the surface of the mercury exposed to the air, which rises or falls with the mercury; and the upper extremity of the rod having a scale adjoining, it acts as an index and shows the height of the liquid within the tube.

406. Safety-Valve.—The object of this valve is to permit the escape of steam, should it accidentally become stronger than the boiler is intended to bear, and thus prevent the bursting or explosion of the boiler. It is a valve so loaded as to open with a pressure of steam, a little more than is necessary to work the engine, and considerably less than the utmost the boiler can bear. This valve does not materially differ from that used in Newcomen's engine. It consists of a lever, the joint or fulcrum of which is set on a support at the side of a short tube or pipe, communicating with the boiler. From the lever immediately over the aperture of the tube, a rod descends, having a plug attached, which closes the tube. To the other extremity of the lever, weights may be attached, at different distances from the fulcrum, which will have power in keeping down the valve or plug, in proportion to their distance from the fulcrum. The force of the steam will tend to push up the plug (valve), and permit the escape of the steam ; the atmospheric pressure, and the weight attached to the lever, will tend to press down the plug, and prevent the exit of steam. The valve will be open or shut, according to the relative strength of these forces acting on it in opposite directions. Its action will be understood from the figure below (fig. 40). In some steam-boat engines, a conical plug is used, from which a rod rises,

on which circular weights are placed, perforated so that they can easily be slipped off or on the rod. The weights are thus placed above the valve, and when set, cannot shift. In the steel-yard valve, the weight slips along the arm of the lever, and thus acts with greater force; just as if more weights had been laid on.

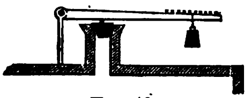

FIG. 40.

407. INTERNAL SAFETY-VALVE.—The valve just described opens outwards. There is another which opens inwards, therefore termed the *internal safety-valve.* The use of this valve is to admit the air to the interior, should the steam be suddenly condensed from any cause. Were there no such contrivance, the atmospheric pressure on the external surface of the boiler (14·7 lbs. on every square inch) might crush the boiler (termed *collapse*) on any sudden diminution of the elastic force of the steam. But the internal valve yields and admits air when the internal pressure on it is much diminished, and thus produces an equilibrium.

APPENDIX.

REMARKS ON CERTAIN STATEMENTS REGARDING THE INVENTION OF THE STEAM-ENGINE, CONTAINED IN M. ARAGO'S HISTORICAL ELOGE OF JAMES WATT.

The following extract from the Minutes of the Philosophical Society of Glasgow, forwarded to me by Mr. Hastie, the Secretary (now M.P. for that city), will explain the publication of the following "Remarks."

4th December, 1839. Walter Crum, Esq., Vice President, in the chair.—As intimated at last meeting, Mr. Hugo Reid read a paper, entitled "Remarks on the statements in Arago's Life of Watt regarding the invention of the Steam-Engine.—Various members having spoken, all in confirmation of the views advocated by the Essayist, it was moved by Mr. Thomas Edington, that Mr. Reid be requested to publish his paper; which motion having been seconded by Mr. Robert Muir, and backed by the unanimous vote of the Society, Mr. Reid acceded to the request.

The Historical Eloge by M. Arago is the first memoir of James Watt which has appeared in a separate form, and, as such, will naturally attract some attention. It comes to the British public backed by the weight and authority of the French Academy of Sciences, before whom it was read; and with another powerful recommendation in the deservedly high name of its author. It is therefore necessary to examine this memoir with care and minuteness, to look at the spirit as well as the letter, and to correct any errors it may contain or tend to create, even at the expense of sometimes appearing hypercritical.

On perusing M. Arago's work, I thought that great injustice was done to Savery and Newcomen, the inventors of the first steam-engines; and that, in various ways, the fame of Watt was lessened, and his labours undervalued. Had M. Arago merely exaggerated the value of what was done by De Caus and Papin,

it would not have been worth noticing; but as it certainly appeared to me that Savery, Newcomen, and Watt, on whom I had always looked as the inventors of the steam-engine, were coldly treated, and even depreciated in the Eloge, I deemed a correction of his errors not an unfit subject to bring before the Philosophical Society of Glasgow, where every thing relating to Watt and the steam-engine is always regarded with peculiar interest. On meeting with the members in the Society Hall, before the paper was read, I found that those who had perused the Eloge were impressed with sentiments similar to my own regarding it. Upon discussing the subject, all appeared to be desirous that some criticism on M. Arago's statement should be brought out, which would have the prominence and publicity that a separate publication would give it.

M. Arago himself seems to have been aware that exceptions would be taken to some of his views. In commencing the historical notice of the invention of the steam-engine, he remarks :—

"I approach this enquiry with the firm determination of being impartial,—with the most earnest solicitude to bestow on every improver the credit which is his due,—and with the fullest conviction, that I am a stranger to every consideration unworthy of the commission you have conferred upon me, or beneath the dignity of Science, originating in national prejudices. I declare on the other hand, that I esteem very lightly the innumerable decisions which have already emanated from such prejudiced sources; and that I care, if possible, still less, for the bitter criticisms which undoubtedly await me, for the past is but the mirror of the future."

REMARKS, &c.

It has always been considered a matter of some importance to ascertain who are the authors of discoveries or inventions which have forwarded the progress of Science and the Arts, and thus proved useful to society. That mankind should ever hasten to do honour to those who have added a new truth to the general stock of knowledge, or placed some new or increased power within their reach, is of importance, as an incentive to genius, were it of no other use. It will undoubtedly be a powerful

stimulus, even though it may often lurk in the breast and not be confessed or distinctly felt; and many a genius, by "chill penury repress'd," or by neglect, will find secret consolation and encouragement in the thought that posterity at least will do him justice, and take some pains to ascertain who is the real author of an useful invention, and distinguish him from those who, from various accidents, may have had an undue prominence assigned to their labours. It is true enough that this, the desire of fame, present or posthumous, is not the highest or purest motive to excite men tò extend the boundaries of Science, and enlarge the powers of Art;—but it is *a motive*, and, certainly, not a bad one; and being of undoubted service to mankind, ought surely to be respected.

The love of justice—the desire to see fair dealing between man and man—is inherent in the human miud. And, however this feeling may be blunted by various causes, such as party animosity, national prejudices, or personal jealousies, during the lifetime of the candidates for fame; it should ever be carefully freed from these when we are considering the character and deeds of those who have passed from this scene, and cannot assert their own claims. Their fame and reputation ought to be held sacred; the only portion they now have in this world should not be touched with a rude hand.

But whether determining the true authors of discoveries be intrinsically important or not, it has become so. From a mixed feeling of pride, curiosity, and a sense of justice, a keen interest has always been taken in such investigations. In all ages and in all countries, distinguished men are considered to have conferred a lustre on their native place, on those spots where they have been educated, or lived and flourished. The sphere of action of those who have rendered themselves illustrious has always been honoured for their sake; and the citizens of every community have been very jealous of the reputation of those of whom they feel proud. This feeling has led to disputes, partaking somewhat of a national character, and conducted, occasionally, with no little keenness and acrimony.

There has been a good deal of discussion between the French and ourselves, as to the invention of the steam-engine. There has been the more room for misunderstanding or misrepresentation on this point, that this great machine was certainly *not entirely*

the production of any one mind, but of many, each working with the vantage ground of the hints or labours of those who preceded him. It is not easy to assign a numerical value to the services of each inventor, and therefore, those who glance at the subject hastily or superficially may easily be led into erroneous views.

All are agreed that to James Watt, the chief honour is to be awarded of having given to the Steam-Engine the great power, and varied utility, which now distinguish it. But there are others, preceding Watt, whose claims have been the subject of contention. And even the fame and merits of Watt himself may be detracted from considerably by giving an exaggerated estimate of the value of the inventions of others; and by associating them with Watt as if on an equal footing; more especially if those who are thus elevated to the same level were on the same track of invention.

In both of these points—1. As regards the respective merits of those who paved the way for Watt, and 2. As regards the merits of Watt himself, I conceive that the memoir of M. Arago calls for some remark.

It will smooth the way very much, in the investigation of the questions before us, to examine shortly the various modes of applying steam as a power, and divide the invention into separate stages as much as possible. This will enable us more easily to come to a judgment on the comparative value of each step. (See the historical analysis in pp. 86-9.)

Such were the *hints, suggestions, discoveries, inventions,* from Hero, 130, B.C. to Watt. All that M. Arago mentions are in the above table, and several that he does not mention. Whether or not they are to be considered as *steps in the development of steam as a power,* the reader can easily judge. I have no hesitation in adducing every one as having aided in paving the way for this great power. It is the degree of merit which ought to be attached to each, which forms the debateable question.

M. Arago leaves out of the catalogue of contributors to the Steam-Engine, all the names whom I have attached to the four first heads in the above table, as not being entitled to rank among the inventors of this great machine, excepting Rivault.* He com-

* Garay and Mathesius are totally omitted, Porta mentioned in a note, only to be rejected, and Hero discarded because he was on a different track from the mode ultimately adopted of applying steam power.

mences with Rivault's experiment, and the proposal of De Caus, whose merits he greatly exaggerates. He omits Nos. 6 and 7. No. 8, the scheme of Papin, is praised evtravagantly, and estimated far beyond its value. Nos. 9 and 10, the schemes of Savery and Newcomen, are half suppressed, slurred over, and unhandsomely depreciated. And, lastly, Nos. 11 and 12, and the labours of James Watt, are slighted and depreciated by various remarks, and by associating Papin with Watt, as if on an equal footing.

M. Arago rejects the scheme of Hero from all place in the list of contributions to the modern engine. As far as regards the mode of applying the power and details of the machinery, this is correct. But it must be evident that Hero's Æolipile, so striking and distinct an exhibition of a moving power or force procured by steam, must have had some effect in directing attention to the useful properties of steam; to the great truth, that a force is procurable by boiling water, and thus have aided in keeping the general idea before men's minds.

After describing the scheme of Hero, and alluding to many obscure hints as to steam power, M. Arago remarks:—

"After these faint glimmerings of the Greek philosophers, we must pass over an interval of nearly twenty centuries, before we meet with any useful notions concerning the properties of steam."—p. 30.*

Thus, "at one fell swoop," we have Garay, Mathesius, and Porta annihilated—Garay, who, at Barcelona in 1543, propelled a vessel on the water without sails or oars "by an apparatus, of which a large kettle filled with water was a conspicuous part,"—and Mathesius, who, in 1571, gave a hint that a powerful machine might be produced by steam, using the graphic terms, "mighty effects could be produced by the volcanic force of a little imprisoned vapour." We do not claim much merit in contributing to the development of steam-power for these, as Garay's plan was never published, and Mathesius did little more than give the hint of a power being procurable by imprisoning vapour, and that it might be applied to a machine. But, as it is clear that they possessed superior knowledge on the subject, and *that a knowledge of what they did or said falling on a congenial soil,* might, by

* Life of James Watt, by M. Arago; Edinburgh, Adam and Charles Black. This edition is referred to throughout.

calling attention to the subject, or even giving the hint for experiments, *be the germ of something useful*, we cannot refuse them a small niche in the temple dedicated to the originators of steam-power.

Garay was a Spaniard; Mathesius a German. It is rather singular, that, while these are doomed to oblivion, M. Arago does not forget to mention "our [his] countryman Gerbert." True, he rejects him from the list (in which he has hardly ever been placed) on the grounds, that his project was not for steam as a force or power; but he is brought forward as author of an invention connected with steam. It appears to me that the few lines occupied in knocking down the *man of straw*, Gerbert, would have been better spent in paying a small tribute to the *true men*, Garay and Mathesius.

Immediately following the passage quoted above, M. Arago proceeds, p. 31 :—

"From that time onwards, experiments, precise, conclusive, and irresistible, took the place of mere idle conjectures.

"In the year 1605, Flurence Rivault, a gentleman of the bedchamber to Henri IV., and the preceptor of Louis XIII., discovered that an iron ball, or bomb, with very thick walls, and filled with water, exploded sooner or later when thrown into the fire, if *its mouth were closed*, or, in other words, if you prevented the free escape of the steam as it was generated. The power of steam was here demonstrated by a precise proof, which to a certain point, was susceptible of numerical appreciation."

This experiment certainly deserves a place in the history of steam. But it is of extremely little value in reference to the Steam-Engine. Its object is a sudden explosive action, not that steady continuous power required in a steam-engine. It was not connected with the action of any machine: it was not, from the violent, uncertain, dangerous nature of the effect, likely to lead others to the idea of steam being used for any steady regulated motion. Rivault had no idea beyond the bursting of the bomb. In itself it was of no value connected with the construction of a steam-engine. Of all the inventors, he was farthest from any thing like a steam-engine, because the power he exhibited was sudden, violent, dangerous, irregular in its action, and therefore farthest from what is wanted in the steam-engine. Rivault only showed that water could be made to produce an effect like gunpowder. Yet this powerful agent was long known without any

attempts to get a steady, continuous power from it; from the evident reasons just stated in reference to water. Keeping in view the important consideration, that a power was wanted which should not be intermitting, and which should be easily regulated; and considering what was done by Mathesius previously, and by Porta about the same time, Rivault seems rather out of place among the inventors of the steam-engine, except in a very secondary rank.

M. Arago then goes on to trace the connection between Rivault's bomb, and the apparatus of De Caus, and remarks, p. 32:—

"For this bomb let us now substitute a strong close boiler of large dimensions, and then there is nothing to prevent our forcing great masses of liquid to indefinite heights by the sole action of steam; and we shall have constructed, in every sense of the word, a steam-engine which might serve the purpose of drainage.

"And now you have been made acquainted with that invention for which France and England have contended, as formerly the seven cities of Greece respectively claimed the honour of being the birth-place of Homer. On the other side of the channel they have unanimously ascribed the honour to the Marquis of Worcester, of the illustrious house of Somerset. On this side, again, we maintain that it belongs to a humble engineer, almost forgotten by our biographers, namely, Solomon De Caus, who was born at Dieppe, or in its neighbourhood."

Of the precise merits of De Caus we shall speak a little further on.

M. Arago then proceeds to show, very summarily, and with a triumphant air, that as De Caus preceded Worcester by many years—"For who can maintain that the year 1615 did not precede the year 1663."—De Caus and not Worcester must be regarded as the inventor or originator of the Steam-Engine;—a wondrous easy task, if the two engines were the same, and if one of them is to be regarded as the first Steam-Engine, two points which M. Arago assumes without any discussion or reason given.

But they were not the same, for in Worcester's Engine there is reason to believe that there was a vessel for generating the steam, distinct from that containing the water to be raised—a most important difference, as we shall see on speaking of Savery's engine. And, we shall find presently, that neither De Caus nor Worcester has claims to a place of any consideration among the contributors to the STEAM-ENGINE.

M. Arago speaks of writers on this side of the channel, as "those whose principal aim seems to have been to remove every French name from this important chapter in the history of Science." This may be believed in France, where British histories of the steam-engine are not much known, and there create a prejudice against British writers as having suppressed the claims of De Caus and others. But it so happens, that almost every British author has not only mentioned De Caus, but given the whole of what that engineer has left on the subject of steam-power, including the drawing of his machine. They may differ among each other, and with M. Arago as to the value of his services. But they have placed the full data before their readers. (See Farey, Lardner, Stuart's work, dated 1829, &c.) M. Arago seems well acquainted with Mr. Stuart's work. In another of this writer's works, of which the third edition is dated 1825, De Caus is fully brought forward.

M. Arago states, "It is exceedingly doubtful whether either Solomon de Caus or Worcester ever constructed the apparatus they proposed."—It is almost certain, from various passages in the writings of Worcester, from some of his acts and those of his widow, from the report of a foreigner, who saw it, and from some Acts of Parliament, that Worcester did construct, exhibit to several individuals, and prove the power of his engine—and that he really had raised large masses of water great heights by it.—And it is certain that the report of what Worcester had done, along with a vague idea of the manner in which he effected it, aided in no small degree in stimulating others to successful attempts to raise water by steam. M. Arago, if he doubts that Worcester constructed a machine for raising water by steam, should have, at least, mentioned that there are many who believe Worcester to have constructed an efficient engine. He might have found strong reasons given for this opinion, in the work of Mr. Robert Stuart. Worcester possessed one point characteristic of an inventor, in which De Caus was deficient. He was aware of, and proclaimed the peculiar value of his invention—brought it out prominently as something great—and by his confidence in its success, must have inspired others with an idea favourable to the application of steam power. Whereas, De Caus mentioned his scheme for raising water by steam only as a thing that might be, among a number of other plans, of

which many were useless, and had far more importance assigned to them than the steam scheme.

But the truth is, that neither Worcester nor De Caus is entitled to the high place that has been assigned to them among those whose hints, or inventions, aided in introducing the use of steam as a source of power ; see pp. 104-5.

And now let us examine particularly the value of De Caus' labours.

In the passage quoted above, M. Arago says, speaking of the bomb, transformed into De Caus' engine,

"We shall have constructed, in every sense of the word, a steam-engine, which might serve the purpose of draining."—p. 32.

And again, in summing up the merits of De Caus, p. 34 :—

"For my own part, I cannot allow that that individual accomplished nothing which was useful, who, pondering upon the enormous power of steam, raised to a high temperature, was the first to perceive that it might serve to elevate great masses of water to all imaginable heights. I cannot admit that no gratitude is due to that engineer who was the first also to describe a machine capable of realising such effects. It ought never to be forgotten, that we can only then correctly judge of an invention, when we transport ourselves in thought to the times when it was proposed, and when we banish from our minds all the knowledge which has been accumulated posterior to its date. Let us suppose some ancient mechanist, Archimedes for example, consulted upon the means of elevating water in a vast close metallic receiver. He would have suggested great levers, pulleys, simple and compound, the windlass, and probably his ingenious screw ; but what would have been his surprise, if, for the solution of the problem, some one had contented himself with a faggot and a match. Who, then, can refuse the title of an invention to a contrivance at which the immortal author of the primary and true principles of statics and hydrostatics, would have been astonished ? This apparatus of Solomon De Caus, this close metallic vessel, in which is produced a moving power almost indefinite, by means simply of a faggot and match, will always maintain a distinguished place in the history of the steam-engine."

It is true that De Caus seems to have been the first to PROPOSE the application of steam to raise water on the large scale.

It is true that De Caus described an apparatus, by which, water put into the apparatus might, by the power of heat, be raised *a little* above it.

1. But it is a mistake to adduce De Caus as the first to perceive that steam could be made to raise water, or as the first who

described a machine which would raise water by steam: or, to represent him as perceiving that steam would raise water by "pondering upon its enormous power."

2. It is a very great mistake to represent the apparatus of De Caus as a steam engine which could in any sense of the word, "serve the purpose of draining;" as a machine capable of realising such effects as "elevating great masses of water to all imaginable heights."

3. Lastly, it is a very great exaggeration of De Caus' idea to speak of it as an INVENTION.

1. De Caus was not the first to perceive that steam could be made to raise water, for, nine years previously (in a work with which there is every reason to believe De Caus was acquainted,*) Baptista Porta had shown that imprisoned steam would raise water. De Caus was not the first who described a machine that would raise water by steam, for Porta had given a description and drawing of a small machine which would effect this purpose, which was on the very same principle as that of De Caus', only on a much better plan. And, De Caus did not perceive this application of steam by "pondering upon its enormous power," as if he had merely known that it possessed power or force, *such as* RIVAULT'S *experiment would show*, and had applied that limited knowledge to the invention of a mode of raising water, by *adding* something, or *varying* the circumstances. Far from it. No pondering, no inventing was needed. He had only to look at Porta's book, where he could see the application and mode of doing it, and a drawing with a detailed description of the experiment.

M. Arago rejects Porta altogether from the catalogue of contributors to the steam-engine. He says (p. 35)—

"The learned Neapolitan *did not speak either directly or indirectly of any machine*, in the passage alluded to; that his object—his only object—was to determine experimentally the relative volumes of water and steam: that in the small apparatus he employed for this purpose, the steam could not elevate the liquid, according to the author's own account, above a few inches;

* Though this is mentioned, it is of little import. We can never tell how far each knew of the labours of his predecessors, and in all the histories of the steam-engine, it is taken for granted that each knew what had been published on the subject previously.

and that in the whole description of the experiment, there is not a single word that conveys the idea that PORTA was aware of the power of this agent, or of the possibility of applying it to the production of a useful working machine."

I am not aware that it has ever been alleged that Porta spoke of a machine—of applying the power to the production of a useful working machine. But he was most assuredly *aware of the power*. His apparatus consisted of a vessel like De Caus; but instead of forming the steam from the water to be elevated, as De Caus did, he formed it in a separate vessel, and introduced it by a tube passing through the bottom into the upper part of the vessel from which the water was to be raised. He says, "the water melting into air will press the water in the case, and this will force the water to rise in the canal [tube] and run out." It is but an indifferent reason for rejecting Porta, that the steam could not elevate the liquid above a few inches in his experiment.* It does not matter, so far as the mere principle is concerned, and that is all we claim for Porta, whether the principle was exhibited for a few inches only or for many yards—if it was clearly shown. All that we claim for Porta was that he furnished the materials which others applied to practice. But the hint was so clear, the plan so distinctly shown by the description and drawing, and the principle so important in reference to the use of steam as a power, that Porta must ever occupy an important place among those who aided in the progress of this great invention.†

It is clear that what Porta did detracts from the merits of those who followed on the same track, reducing De Caus to the humble office of suggesting to do with larger apparatus and larger quantities of materials what had already been done on the small scale—from an inventor to a copyist. Hence, there is some advantage to De Caus by throwing Porta into the shade.

* De Caus' apparatus would not elevate the water above one or two feet. His force pipe terminated a little above the vessel containing the water to be raised.

† Mr. Robert Stuart, in his very instructive and entertaining work, "Historical and Descriptive Anecdotes of Steam-Engines," remarks of Porta —"The author, it is admitted made no application of his apparatus as a mode of raising water directly by the force of steam, from rivers and fountains; but his *diagram* and description are so complete, that its application to this purpose by another, could not be considered even as a variation of his idea.

But I believe very few will concur with M. Arago in omitting, when tracing the progress of steam-power, the individual who first made known, whether in an apparatus for the pocket, or in a colossal boiler, whether he proposed to apply it to practice or not, the property which first led to the useful application of steam. And Baptista Porta was the first who showed that imprisoned steam would raise water. M. Arago himself gives an instance of the correctness of this view. He remarks of Hero's "Æolipile," which was not suggested for practice, but merely a philosophical experiment, "Were, however, the reaction of a current of steam ever to become practically useful, it would unquestionably be right to trace the idea back as far as Hero."—Surely; and let the same principle be applied to Porta, the Neapolitan, even though it does detract something from the genius of De Caus, the Frenchman.

2. It is a great mistake to represent the apparatus of De Caus as "in every sense of the word a steam-engine which might serve the purpose of draining," as a machine capable of realising such effects as "elevating great masses of water to all imaginable heights."

These statements regarding De Caus' apparatus require great qualification, particularly the former. The machine of De Caus was no more capable of realising any useful end than Porta's. It was only fit for a toy, or for an experimental illustration. We are not to consider it as an useful machine, because De Caus loosely spoke of it as such.*

How could a machine serve the purpose of drainage which needed the water to be put into it by manual labour; which, from the application of the heat directly to the water to be raised, rendered it necessary that only a small apparatus and a small quantity of water could be used at a time. De Caus' plan was worth nothing without the separate vessel for generating the steam. And even when this was added, and the machine perfected by many experiments and contrivances, it was found unfit for drainage. The raising water by the direct application of steam only, has not succeeded. And the only part of the engine of Savery,

* Most probably, could De Caus explain his views to us, he *would complain of being represented as describing a machine*, when he only intended to exhibit the general idea and illustrate the power. The slight and loose way in which it is adduced, confirms this idea.

who followed on that track, capable of economical application, is that in which the water is raised by the atmospheric pressure, the steam being employed as a means of procuring a vacuum.

3. Lastly, it is a very great exaggeration of De Caus' idea to term it an invention.

De Caus did not *invent*, did not *add*, *vary*, or *adapt*. No *new power*, no *new combination*, came from him. The machine even upon the plan he described, was not workable from the want of the steam-generator. And without combination with another principle (water rushing into a vacuum procured by condensing steam) it could never be applied to use.

The reader can now judge whether or not it is great exaggeration, and detracts from the merits of those who followed, to speak of De Caus' illustrative apparatus as a "steam-engine," as one which in every sense of the word might serve the purpose of drainage, as capable of useful application, as fit to elevate "great masses of water to all imaginable heights,"—as "an invention, at which the immortal author of the primary and true principles of statics and hydrostatics would have been astonished." Archimedes would have been indeed astonished that it should have been termed an invention at all; that so inefficient an apparatus should have been proposed by one who had before him the far superior model which Porta furnished.

But we hardly do justice to De Caus in supposing that he intended what the indiscreet zeal of some of his countrymen have claimed for him—the invention of a machine for raising water. He merely suggested the use on the large scale of a machine previously described, and gave an *illustration* of its power.

Porta's experiment and drawing, then, pointed out the principle and method of applying it. De Caus proclaimed, *this may be made useful.* We attach no value whatever to his drawing or machine. The suggestion of the application on the large scale, is all that we owe to De Caus. That was certainly an important step. But Porta ought not to be forgotten. De Caus is not to be considered the inventor of a machine capable of giving effect to his suggestion, thereby exaggerating his merits, and detracting from those of Savery, who followed, and worked out the idea into a practicable form. De Caus was no inventor, so far as the steam-engine was concerned. Savery was the first to go beyond the bare idea, to construct a serviceable engine. He did so by

inventing some things new, by combining ingeniously together, in a new way, a number of beautiful contrivances, by knowing the value of his plan, having confidence in it, labouring long to perfect it, publicly advertising and proclaiming it as something new and important, by instructing men how to form it, and bringing it into operation. *Some* qualities of that kind are necessary to constitute an inventor.

We now come to Savery, the next in order to De Caus, upon the plan of raising water by steam directly applied. Of this highly ingenious and successful inventor of the first steam-engine, M. Arago speaks as follows, p. 35 :—

"It is exceedingly doubtful whether either Solomon De Caus or Worcester ever constructed the apparatus they proposed. This honour belongs to an Englishman, to Captain Savery. I have no hesitation in associating the machine which this engineer constructed in the year 1698, with those of his two predecessors, although it must be added he introduced some important modifications; and among others, that of generating the steam in a separate vessel. If it signify little as to principle, whether the motive steam be produced from the water which is to be raised, and in the interior of the same boiler in which it is about to act, or, whether it be produced in a distinct vessel, whence it is at will to be conveyed by means of a communicating pipe and a stop-cock, to the surface of the liquid proposed to be raised, it is very different in a practical point of view. Another and a still more important change introduced by Captain Savery, will more appropriately find a place in the remarks we shall presently devote to the labours of Papin and Newcomen.*

"Savery entitled his work *the Miner's Friend;* but the miners seemed scarcely to appreciate the important compliment he paid them. With one solitary exception, none of them ordered his machines. They have only been employed in distributing water over the different parts of the palaces, of country houses, parks, and gardens, and they have not been used to raise water to a higher level than ten or fifteen yards. It ought also to be observed, that the danger of explosion would have been great, if the immense power had been employed, which their inventor contended might be realised.

"Although the practical success of Savery was so far from being satisfactory, yet the name of this engineer should ever hold a distinguished place in the history of the steam-engine."

* This still more important change introduced by Captain Savery is not described in any other place, as promised above. It probably refers to the raising the water in the first instance by the atmospheric pressure acting into a vacuum procured by condensing steam: and if it be this, it is to be remarked that Savery is not indebted to any one for it—except in so far as the general truth that a vacuum is procured by condensing steam, is concerned.

This is all that is said of the *first steam-engine*, that is, of the first machine which was introduced into practice—the first which went beyond the suggestion or illustration of the power—one which embraced new inventions and new combinations, and a *number* of complicated parts ingeniously adjusted—which was, in every respect, at an immense distance from anything done previously—and which is still in use, and that, too, chiefly in M. Arago's own country.

Savery's machine embraced the important addition of a separate boiler or steam-generator, without which, any apparatus could only be looked upon as an *illustration* of the power of steam. And this was something more than a mere practical detail; for, by having a separate boiler, a small quantity of water heated, sufficed to raise a large quantity, whereas, when the heat is applied to the water itself to be raised, the whole mass has to be raised in temperature to the boiling point; which would limit the power very much, independent of its inconvenience.

Also, Savery's machine embraced the absolutely essential contrivance by which the water was got into the vessel from which it was to be driven upwards by the force of steam. It is very easy to force the water upwards from a close vessel by steam, as De Caus and Porta had shown—*but how was the water from the river, pond, or mine, to be got into the close vessel* where the steam-power was to act. Savery resolved this grand difficulty, by using the atmospheric pressure to force the water (by simply having a tube from the forcing vessel dipping in it) into a vacuum produced by condensing steam; and at the same time raised the water 26 feet. *This was new, as applied in that manner;*—and the combination of the two was one of those happy thoughts which show high inventive genius.

Savery's engine embraced the beautiful adjustments of boiler and double steam-vessels, condensing apparatus, and valves to adapt the suction pipe and force pipe to each other. The number of parts, their simple and happy adjustment, rendered it a perfect and very beautiful machine; capable of the ends for which its inventor designed it; fit for important practical purposes; not becoming *so extensively useful* as he designed it, only from the secondary consideration of the cost of working it; and not coming into general use, because a better plan was shortly discovered (Newcomen's); *but still occasionally used.*

The reader can now judge of the extent to which, in letter and in spirit, M. Arago has, in the case of Savery, displayed an "earnest solicitude to bestow on every improver the credit which is his due."

In the *first* place, the author of this novel, ingenious, *effective*, and very beautiful invention, is most unfairly described as merely constructing the apparatus shown in the crude project of De Caus. (See beginning of extract, p. 253.) I well recollect, in studying for the first time the history of the Steam-Engine, how much I was struck with Savery's elegant engine, and delighted to arrive at last at something tangible, something showing inventive genius, consciousness of the value of the new power, fertility of resources in combining and adding so as to make it a working machine—in alighting at last on A STEAM-ENGINE, after the obscure hints of his predecessors, the mere suggestion of De Caus, and the vain boastings of Worcester. I believe a like feeling will arise in every unprejudiced mind on becoming acquainted with the beautiful, and masterly, and effective engine of Savery: and I trust that there are very few who know the facts of the case, who would represent this very ingenious mechanician, *as merely constructing* the crude machine hinted at by De Caus.

Secondly, We are told that the first steam-engine ever constructed, and still used, was *only* employed to raise water for gardens, and *not above ten or fifteen* yards, and that it was very liable to explosion, "if the immense power had been employed which their inventor contended might be reached." Cold praise this, for the first realisation of what it had taken centuries of hints, suggestions, and experiments, to bring into operation! Singular expressions, "*only*" and "*not above* 30 or 45 feet!" as applied to the first engine that ever did any thing at all;—when we should have expected some enthusiasm, some expression of admiration, from one who is writing the history of an invention—when, instead of pointing out *how little*, we should have expected the historian to have dwelt with pleasure on *how much* Savery did—when instead of being told that there would be risk of explosion if *all* the inventor had anticipated had been done—we would have naturally thought on how much could be, and is done, by using the steam only as a means of making a vacuum, without the slightest risk of explosion.

The awarding praise in general terms to Savery is of little

value, when the contributions of others are specially described and honoured; and what *he* did is slurred over, or omitted, or depreciated, or "damned with faint praise." The reader of M. Arago's sketch of Savery's engine, will learn little more of Savery, than that he constructed the machine which De Caus planned, and that it was a failure; and will rise with a poor idea of Savery's inventive genius, with nothing definite on his mind whereby to remember Savery, or give a foundation for the "distinguished place" M. Arago pretends to assign to him in the history of the Steam-Engine. I cannot avoid coming, then, to the conclusion, that the impression of Savery conveyed by M. Arago's statements is unfavourable, that it is far below his merits, and therefore unjust, and that it is founded on omission and misrepresentation.

After thus summarily disposing of Savery, M. Arago comes to Papin, his chief favourite, to establish whose supremacy, Savery and Newcomen are deposed, and Watt robbed of half his glory.

In p. 37, M. Arago observes :—

"Hitherto we have spoken only of machines whose resemblance to the steam-engines of the present day may be more or less disputed. Now, however, we come to the consideration of the *modern steam-engine*, which performs so important a part in our manufactories and steam-vessels, and is essential in almost every pit and mine. We shall see it commence, enlarge, and develop itself, at one time under the inspiration of some celebrated genius, and at another, under the mere spur of necessity; for 'necessity is the mother of invention.'

"The first name which we encounter in this new period, is that of Denis Papin. It is to Papin that France owes the honourable rank she may claim in the history of the steam-engine."

Papin can only be regarded as the first in the history of the modern steam-engine, inasmuch as he proposed to combine the plan of procuring power from the atmospheric pressure by making a vacuum below a piston—with the plan of procuring that vacuum by the condensation of steam. The above quotation would almost indicate that he invented these contrivances. But this is very far from being the case. It should be known that Otto Guericke, the inventor of the air-pump, had devised the contrivance of producing an active power from the atmospheric pressure, to be applied to useful purposes, by making a vacuum below a piston in a cylinder; producing the vacuum, however, by the laborious

efforts of an air-pump,—and that Porta, if not many others, had shown that a vacuum was produced by condensing steam. Of these, M. Arago says nothing, leaving us to suppose that these contrivances had been *invented* as well as *combined* by Papin.

The idea of combining them was truly a happy thought, to whomsoever it belonged ; and Papin, so far as we know at present, seems to have been the first who did so fully. But I think it will appear very evident that his services have been overrated and his merits exaggerated by M. Arago, when we attend somewhat more particularly to what Papin really did, and what was left undone by him.

Papin, then, suggested that a machine might be constructed in which the piston in a cylinder would be depressed by atmospheric pressure, a vacuum having been made below it by condensing steam. He had not the idea of a separate vessel for generating the steam ; from which, owing to the alternate removal and application of heat, his machine was rendered perfectly useless. He condensed the steam by means of the slow action of the cool air outside of the cylinder, which alone would prevent his engine ever being of any value. He had no beam or convenient mode of transmitting the power procured by the descent of the piston. And not only did he not succeed in his project,—*he condemned his own scheme, by totally abandoning it, and labouring at an entirely different mode of applying steam power* to accomplish the same end,—raising water.

Such being the facts of the case, it is rather startling to be told, as in a passage to be quoted more fully immediately, that Papin "consecrated his life" to the above scheme, or, in the passage already quoted, that "Papin remarked that the end might be obtained 'by different constructions which might readily be conceived,' but left the constructions entirely unexplained. He devolved upon his successors both the merit of applying his pregnant conception, and that of discovering those details which alone can ensure the success of a machine,"—as if he merely suspended the prosecution of his scheme from want of leisure, being still confident of its success, and imparting that confidence to others. M. Arago could not but be aware that Papin, instead of labouring at his project with that steadiness, and perseverance, and hope, which a real knowledge of its value, and a firm conviction of its being the true scheme, would inspire, and transmitting

it to others with the weight and sanction of his name, all of which the expression "consecrated his life" implies—completely abandoned it; and that so far as it was handed down to others, it came with the condemnation of its inventor. This little circumstance, which M. Arago does not mention, has the effect of impressing us with a higher opinion of the genius of those who followed Papin, perceived the value of his project, and worked it out. But these,—Newcomen and Cawley,—of whom we shall say more immediately, have not had the fortune to fall into the good graces of M. Arago.

All these circumstances, of which no mention is made in the "Eloge," detract somewhat from the genius of Papin, so far as is connected with the steam-engine, lessen the value of what he contributed to aid his successors in the invention of this great machine, and give altogether a somewhat different view of Papin's services from that conveyed by the imposing manner in which he is spoken of by M. Arago. There is some little difference in regard to the value of a project which is only useful as a hint to others, between consecrating one's life to it, and trying it for a little and then throwing it aside entirely, for some other means of obtaining the same end. No disrespect to Papin is meant. He was undoubtedly a man of considerable mechanical genius, and of great service in forwarding the progress of steam-power; but he should not be elevated to too high a level, especially when others must be sacrificed to raise him thus to a place which is not his due.

We shall have to recur to Papin in reference to Watt. Let us now pass, as M. Arago does, to the famous atmospheric engine, the work of Newcomen, who followed Savery and Papin. And here we have to complain of very great injustice to the real inventors of the first of what M. Arago calls *modern steam-engines*.

M. Arago's description of the engine of Newcomen is very brief; we shall quote it:—

"In the year 1705, fifteen years after the publication of Papin's first memoir in the Acts of Leipsic, Newcomen and Cawley, the one an ironmonger, and the other a glazier in Dartmouth, Devonshire, constructed (and mark, I do not say projected, which is a very different thing), I repeat constructed a machine, which was meant to raise water from great depths, and in which there was a distinct vessel where the steam was generated. This machine, like the small model of Papin, consisted of a vertical metallic cylinder, shut at the bottom and open at the top, together with a piston,

accurately fitted, and intended to traverse the whole length, both in ascending and descending. In the latter, as in the former apparatus also, when the steam was freely admitted into the lower part of the cylinder, so filling it, and counterbalancing the external atmospheric pressure, the ascending movement of the piston was effected by means of a counterpoise. Finally, in the English machine, in imitation of Papin's, so soon as the piston reached the limit of its ascending stroke, the steam which had impelled it was refrigerated; a vacuum was thus produced throughout the whole space it had traversed, and the external atmosphere immediately forced it to descend.

"To produce the necessary cooling, Papin, as we have already stated, did nothing more than remove the brasier which heated the bottom of his small metallic cylinder. Newcomen and Cawley introduced a process greatly preferable in every respect. They caused a large quantity of cold water to flow freely in an annular space formed between the external wall of the cylinder of their machine, and a second cylinder somewhat larger, with which they surrounded it. The cold communicated itself by degrees to the whole thickness of the metal, and finally reached the steam itself.

"Papin's machine, thus perfected in so far as regarded the method of cooling the steam, or of condensing it, excited in a high degree, the attention of mine proprietors. It was rapidly introduced into many counties in England, where it was of considerable service.

This is the whole description of the atmospheric engine, excepting some allusion to the plan of condensing the steam by an interior jet, and to the engine being made to open the stop-cocks itself, the latter of which was not the invention of Newcomen and Cawley, and need not be alluded to here.

According to the preceding statement, the only thing of consequence done by Newcomen and Cawley, was, condensing the steam in a better mode than Papin—"Papin's machine, thus perfected in so far as regarded the method of cooling the steam." —"They constructed (and mark, I do not say projected, which is a very different thing)." One would hardly suppose from M. Arago's statement that they did any thing more than cool the steam in a better way. But let us examine what Newcomen and Cawley did.

They perceived the capabilities of Papin's suggestion and crude machine, after it had been abandoned and thereby condemned by the individual who, above all others, was to be expected to know its value—its author. They persevered in labouring to render it workable, although dissuaded by Dr. Hooke, one of the mechanical authorities of the time. There, surely, we must recognise some of the qualities of an inventor. But not a word of these circumstances is to be found in M. Arago's history; not a syllable of

praise for Newcomen and Cawley. They are, on the contrary, treated with a sneer, for I presume it is to them M. Arago alludes, when he states of the modern engine, "We shall see it commence, enlarge, and develop itself, at one time under the inspiration of some celebrated genius, and at another, under the mere spur of necessity: for 'necessity is the mother of invention.'" Papin and Watt are prompted by genius: Newcomen and Cawley were the only others connected with the modern engine; but they had no merit!—the mere spur of necessity did their part!

They projected the formation of the steam in a separate boiler, and contrived ingenious methods for supplying and cutting off the steam, feeding the boiler with hot water from the cylinder, &c. They projected and adjusted a method for expelling the air in the cylinder, and that which entered with the steam. They contrived a method of keeping the piston tight, by pouring water above it, a difficult matter then. They projected a plan of supplying the very important point of an easy method of transmitting the motion from the piston, in the beam playing on a pivot. They projected a mode of cooling the steam sufficiently fast to make the engine workable. They introduced (it is of no consequence whether it was an accidental discovery or not) the excellent method of condensing the steam by projecting cold water amongst it. They made the machine itself raise the water for the boiler and for the condensation, which involved some ingenious adjustments. They laboured assiduously for years at adjusting the proportions of the parts. They brought it into operation, and it was successful. All this they did, out of the crude project which Papin had abandoned. And in the face of all these circumstances, which were or ought to have been known by one who writes on the history of the steam-engine, we are told of the authors of this complex, ingenious, elaborate, and working machine, that they only constructed, did not project it; that it was the bare idea of Papin "perfected in so far as it regarded the method of cooling the steam!"

When the number of parts required to make the atmospheric engine effective are considered, and the exceedingly limited means Papin gave to work upon, and when we bear in mind that Papin so totally abandoned it, we must consider those as the chief inventors who made it work, and award them far higher praise

than Papin, who merely suggested the combination of two schemes already known, could go no farther than that bare idea, and deserted and disclaimed his offspring at the very time these individuals saw its value, and by additions, new combinations, and laborious experiments, worked the principle into a practicable shape.

It would be difficult to understand why there seems to have been such anxiety to throw Newcomen's engine as much as possible out of view, why there is not a single expression of praise or admiration awarded to it—for Newcomen might receive high praise, and Papin's works be appreciated too—did we not perceive that it is desired to elevate Papin to a level with Watt, which can only be done by throwing into the shade the intermediate inventor, Newcomen. We shall find that this determination to elevate Papin has led M. Arago to what he surely cannot have intended, namely, to depreciate the subject of his Eloge, the man whom he is especially professing to honour!

But this is not all. M. Arago cannot part with the atmospheric engine, so grand a project in Papin's hands, who did not succeed with it, and so poor a thing in Newcomen's, who brought it into use, without an additional kick.

He remarks, p. 45, in dismissing Newcomen's engine, and introducing Watt's inventions—

> "There exist in the museums of the curious, a considerable number of machines from which industry had anticipated great things, but which the expense of working and keeping them in order has rendered little more than mere objects of curiosity. Such, in all probability, would have been the fate of Newcomen's machine, at least in those districts which were not rich in fuel, had not the labours of Watt, which I must now proceed to analyse, succeeded in conferring upon them an unlooked for perfection."

To represent Newcomen's engine, as a curious speculation, a theoretical project, a thing to be shelved in a museum,—is to ignore the engineering history of the greater part of the last century.

Industry not only anticipated, but actually received great benefits from Newcomen's engine. It was fortunately superseded at last by Watt's, a more powerful and more economical engine: but if no better had been invented, Newcomen's engine would have been everywhere in use and of the highest value at this

day. For *it was an effective engine, both as regards the mechanism and the expense of working it, and a better means of raising water than the other methods then in use.*

Tredgold, speaking of Newcomen's contrivances, says "that they produce all the difference between an efficient and an inefficient engine." Newcomen's engine was the first really efficient steam-engine—that is, the first engine which could be applied *profitably* and *safely* to the more important purposes for which such machines were required at the time of its invention. It is still occasionally ordered, for situations where fuel is cheap, the first cost being comparatively small. It is fitted with a condenser, separate from the cylinder, by which its action is much improved.

Though now superseded by Watt's, Newcomen's engine ought not to be forgotten. Even had it never come into use, its value, as a great step in the progress of invention—as the raw material out of which Watt constructed his admirable engine—cannot be too highly estimated. But it was a machine of great practical utility. It came into operation about 1712, and continued to be used exclusively for nearly seventy years (till about 1778—80); and for a considerable time afterwards was much employed. In 1797, it was still so much in use and so much esteemed, that a work was written upon it by Mr. Carr. Thus, for nearly a hundred years, it was the chief hydraulic machine; and it was a century of unusual activity—of awakening energy in arts and manufactures. When it was first introduced, many valuable mines could not be worked on account of the accumulation of water. This engine not only rendered these available, but enabled others to be deepened and new ones to be opened, which could not have been done without some powerful means of raising water, cheap, safe, and manageable; which was not known till Newcomen's engine appeared. His engine was soon applied and continued to be used with great advantage in the coal-mines of the north of England, the tin and copper mines of Cornwall, and the lead mines of Cumberland, &c. It was employed in cities for supplying the inhabitants with water; in 1752 and afterwards, it was used for raising water to drive water-wheels for mills; it was used for blowing the air into the blast-furnaces for smelting iron-ore; and was soon taken advantage of on the continent for similar purposes.

When these things are borne in mind, we must admit that

society is under no small obligations to the inventor of a machine which, for so long a period, was an essential agent in procuring an adequate supply of materials absolutely neccessary to a world advancing rapidly in numbers and civilisation ; and that any one who can speak of Newcomen in such depreciating terms as we have seen, has yet a good deal to learn of the history of the steam-engine, and some considerations to dismiss from his mind before he can give "every improver the credit which is his due."

We now arrive at the last head of our complaint against M. Arago's "History of the Steam Engine;" that referring to Watt himself. The following passages contain the statements by which we conceive Watt's rights are injured and his fame lessened.

P. 14. "The principal discovery of our associate, consisted in a particular method of converting steam into water."

There is a looseness in expression here, which, taking the passage by itself, may convey a very limited view of Watt's first improvement, the separate condenser. The mode of condensing the steam was the same previously employed—viz. throwing a jet of cold water amongst it. Watt's happy thought was the idea of *causing the steam in the cylinder to rush of itself out of the cylinder*, by keeping up a constant vacuum in an adjoining vessel communicating with the cylinder. When the steam arrived at the condenser, it was turned into water in the usual method. M. Arago explains it more correctly afterwards. But those who have a high admiration for Watt's genius may be excused in cautioning against a misapprehension which might, by any possibility, detract from the fame of this illustrious man.

It may be observed, too, that the double acting engine, and expansively acting engine, were fully as ingenious, and the former as important as the separate condenser.

In page 38, the following statement occurs, the closing lines of which will surprise all who know anything of Watt's inventions.

"Now, we find that it was to the production of an economical moving power, capable of effecting the unceasing and powerful strokes of the piston of a large cylinder, that Papin consecrated his life. The procuring afterwards from the strokes of the piston, the power requisite to turn the stones

of a flour mill, the roller of a flatting mill, the paddles of a steam-boat, the spindles of a cotton mill; or to uplift the massy hammer, which, with oft repeated stroke, thunders upon the enormous masses of red-hot iron, just taken from the blast-furnace; to cut with great shears thick metal bars, as easily as you divide a riband with your scissors; these, I repeat, are problems of a very secondary order, and which would not embarrass the most common engineer.

These problems, which, it is stated, would not embarrass the most ordinary engineer, were a stumbling-block to Smeaton, long after Papin's idea had received all the perfection of which it was capable; and they involve Watt's happiest efforts—the invention of the double acting engine, sun and planet wheel,* and parallel motion; and the application and adjustment of the crank, governor, fly-wheel, &c.

Surely, M. Arago cannot have been aware of the circumstances—that Watt's latest and finest inventions were those which adapted the power from the unceasing strokes of a piston to the very objects M. Arago mentions—that is, generally speaking, to procuring a smooth, equable, rotary motion, capable of being easily and quickly increased or diminished in power, without any violent shock or derangement of the parts—and that this had long been a desideratum in practical mechanics. The effect of the above statement is very disparaging towards some of the happiest efforts of Watt's genius.

Again, M. Arago states, p. 90:—

"I do not know if Homer and Aristotle, if Descartes and Newton, would appear in the eyes of these new Aristarchuses, worthy of a simple bust; but assuredly they would refuse even a modest medal to our Papins and Vaucansons, our Watts and Arkwrights, and to other mechanists, unknown, perhaps, in a certain circle, but whose renown will go on augmenting from age to age with the progress of knowledge."

In p. 103, we find:—

"This, gentlemen, is a very abridged sketch of the benefits bequeathed to the world, by the machine of which Papin supplied the germ in his writings, and which, after so many ingenious exertions, Watt carried to such admirable perfection."

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* Watt proposed to convert the reciprocating motion of the beam into a continued circular motion by means of the crank. He was anticipated taking out a patent (unfairly it has been said), and invented the *sun and planet wheel* as a substitute.

And in the same page :—

" We have long been in the habit of talking of the age of Augustus, and of the age of Louis XIV. Eminent individuals amongst us have likewise held, that we might with propriety speak of the age of Voltaire, of Rousseau, and of Montesquieu. I do not hesitate to declare my conviction, that, when the immense services already rendered by the steam-engine shall be added to all the marvels it holds out to promise, a grateful population will then familiarly talk of the ages of Papin and of Watt."

The associating Papin and Watt together, as in the three preceding extracts, is almost too absurd in reference to Watt, to require more than pointing it out.

Why, in this enumeration of the landmarks of an era, is Newcomen forgotten? And why is Papin so elevated, who simply combined two ideas previously in existence, and could not go beyond the bare idea; who was never able to work out his idea, and finally abandoned it to seek for other modes of attaining the desired end? Why is Newcomen omitted, who perceived the capabilities of this scheme at the very time when it was abandoned by its parent, and generally comdemned; who, by an elaborate series of experiments, and many ingenious contrivances and applications, brought it to a working state and introduced it into practice?

And is it not lowering Watt to place him on the same level with *any* of his predecessors, more particularly with one who did so little as Papin? Watt not only suggested a new and beautiful principle (causing the steam to rush of itself into an adjoining vessel), fully equal in novelty and in genius to Papin's bare proposal to combine the schemes already known; but gave practical effect to that principle, and extended immensely its range of application by a number of the most ingenious, beautiful, and novel mechanical contrivances. Besides the numerous mechanical inventions, including the double acting engine, Watt developed *new properties* of steam, not only important in their applications, but showing high inventive genius in their discovery —namely Nos. 4, 5, 6, and 7, in page 85. Papin invented nothing —developed no new idea. Watt showed extraordinary fertility of resources in meeting many difficulties which the more complex structure and more extended applications of the engine offered to him. Papin was unable to go beyond the first crude notion

which struck him. Watt brought his machine into such a state, not only inventing new principles, but extending and adding so much to it, that seventy years' experience has suggested no material alterations. Papin merely proposed the sufficiently obvious combination of two principles already before him, left the proposed machine in a totally unfit state for practice, and with so many defects and difficulties, that it was not likely to suggest much to others, more particularly as it was transmitted with its author's condemnation.

Such being the comparative merits and services of Papin and Watt, we leave the reader to judge whether or not we err, in pronouncing it a monstrous exaggeration, to associate Papin with Watt as if on an equal footing—whether or not the doing so, more particularly when the former is described as furnishing the germ of an engine which the latter carried to perfection, is not a gross injustice to Watt, and has the effect of robbing him of half of his glory.

To speak of "the age of Papin," is truly extravagant. Indeed, it is not likely that ages will be characterised by the leading inventors—by those who distinguished themselves for mechanical genius. Eras will always be marked, as they hitherto have been, by the names of those who have given a stimulus to mind—those who, by their writings or their deeds—such as statesmen and political authors, poets, moral writers—tend to advance mankind as intelligent beings,—to work out a moral revolution. But since M. Arago estimates mechanical services so highly, may we suggest to him that there was an inventor called Savery, who produced the first working substitute for horse-power or water-power in raising water ; and that there were seventy years, which, if an era is to be marked by the name of him who supplied the most effectual means of procuring *power*, most persons would term "the age of Newcomen."

M. Arago takes much pains to show the wonderful effects which have flowed from Watt's inventions. He asked more than a hundred people of all classes and all parties in Britain, "What is your opinion of the influence which Watt exercised upon the wealth, the power, and the prosperity of England ?" and he mentions that they all united in placing the services of "our associate" above all comparison ! M. Arago need not have given himself

any trouble on this point, as no one ever disputed, what is, indeed, perfectly self-evident, that the improvement of the engine for raising water, and the invention of the engine for propelling machinery, were followed by most important results. But I do not think the eulogist of Watt should insist too much upon this point, or should occupy much of his pages with praise awarded because great results have flowed from his inventions, while the invention itself is somewhat briefly sketched. It is apt to distract our attention from the true source of admiration for Watt,—the genius displayed in his inventions. The mariner's compass, and gunpowder, produced, in their day, nearly as important results as Watt's inventions ; but we do not therefore regard their discoverers as men of genius. Printing produced more important consequences than any other invention ever did, or is likely to do ; but we do not therefore consider Gutenberg as a genius of a higher order than Watt. Far from it : every person knows that any one of Watt's inventions displayed more creative power than the discovery of the art of printing. I cannot but think, therefore, that we should have been impressed by M. Arago with a higher opinion of Watt's genius, if a somewhat less portion of the "Eloge" had been devoted to enforcing, by striking illustrations, and an imposing array of figures, and the opinions of men who were no judges of Watt's inventions, the very obvious truth that a cheap and effective power was of immense value to society—and if the number of beautiful inventions by which that end was attained, had been more minutely explained, and more warmly eulogised. It is upon these that the true admirer of Watt will dwell with pleasure and enthusiasm ; and I regret to find that in M. Arago's "Eloge," their ingenuity, novelty, and beauty are not brought out and expatiated upon with that fulness, admiration, aud warm praise that was to be expected, and that is displayed in other places where it is less called for.

In conclusion, then, it appears—

1. That M. Arago has omitted from the list of contributors to the application of steam as a power; Garay, Mathesius, Worcester, and Morland, all of whom, in some degree, forwarded the progress of this great invention.

2. That far too high a value is set on the bomb-bursting experiment of the Frenchman Rivault.

3. That Porta, the Neapolitan, who first showed clearly the force of confined steam, who showed its power exerted in raising water, the object which first led to the useful application of steam, who gave a drawing of a small apparatus, and a description, to which nothing was wanting but the idea of use on the large scale, is unfairly dealt with in being excluded altogether from the catalogue of contributors to this gradually progressing invention.

4. That by keeping Porta out of view, a much higher idea must be entertained of the merits of De Caus than he is entitled to; standing forth as the inventor of a mode of raising water, while he only suggested the use of a project already in existence.

5. That the value of the hint of De Caus, the Frenchman, is highly exaggerated; and that to speak of him as describing a machine fit for any service, is to detract from the merits of Savery, the Englishman, who invented, described, and first constructed a steam-engine on that plan.

6. That the merits of Savery, whose engine included an important point (separate boiler,) wanting to render De Caus' scheme of any use, and another principle, differing altogether (vacuum by steam, and suction pipe), are slurred over, and depreciated, his machine not fairly explained, and that he is erroneously represented as merely constructing the engines described by Worcester and De Caus.

7. That the services of Papin are greatly over-rated by describing him as the inventor of a machine which he never constructed, and abandoned in a crude and useless state; by omitting to state that the two principles he combined were previously known; and by associating him with Watt.

8. That very great injustice is done to Newcomen and Cawley in representing them as constructing, not projecting, the engine which bears their name; in speaking of their engine as Papin's merely perfected in one point; as the result of the mere spur of necessity; as a mere object of curiosity to be shelved in a museum; as an engine from which industry had anticipated great things, but had been disappointed; and in associating Papin and Watt to the exclusion of the inventors of the atmospheric engine.

9. That great injustice is done to Watt, in stating that the chief of his inventions are but problems of a secondary order, which would not embarrass the most common engineer ; and in associating Papin, whose contribution was so meagre and imperfect, confined to one single point, and that made up of previous schemes—with Watt, whose fertility of genius added so many new, beautiful, varied, and important inventions.

THE END.

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